JOURNAL

OF THE

FRANKLIN INSTITUTE.

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXIV. OCTOBER, 1882. No. 4.

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MOHR'S GRAPHICAL THEORY OF EARTH PRESSURE.

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The subject of the pressure of earth has been worn nearly threadbare. It has been discussed from all points of view, again and again, until there seems no room for anything new to be presented. And yet, although our technical journals have had their full share of the discussion, the writer does not remember ever to have seen in English a presentation of the graphical method given by Professor Mohr in 1871. The analytical methods in general use, either the ones founded on the wedge of greatest pressure, or on the principles of internal stress, as first presented by Rankine, although simple enough, and although leading to formulas which can easily be interpreted graphically, often leave some confusion in the mind; and they are far inferior, as regards giving a clear and connected view of the subject, to Professor Mohr's method. The practical engineer who should happen to be unacquainted with the method will be glad to learn that the whole subject of the pressures in a mass of earth bounded above by a plane can be represented clearly and concisely without the use of any but the simplest mathematics, and with the aid of only the most elementary theorem of statics; and that the method leads to very simple methods of

finding the pressure on a wall in any position. It may not be amiss, then, to bring up the subject once more, and to explain the method; and we shall have occasion to notice the limits of its applicability. The present paper, then, contains nothing original, for the method is widely known and has been often discussed. It is presented in the following pages in my own way, but it may all be found in the following publications:

1. "Mohr—Beitrag zur Theorie des Erddrucks. Zeitschrift des Architekten-und Ingenieur-Vereins zu Hannover, 1871."

2. "Mohr—Zur Theorie des Erddrucks." Same periodical, 1872.

3. "Winkler—Neue Theorie des Erddrucks, nebst einer Geschichte der Theorie des Erddrucks und der hierüber angestellten Versuche." (Vienna, 1872. R. v. Waldheim.)

We assume from the beginning an unlimited mass of earth with a plane upper surface, and neglect the cohesion. The following results follow at once:

1. The pressure on any plane parallel to the surface is vertical, and equal in intensity to $\gamma\, y$, if γ is the weight of a unit of volume of earth, and y the normal distance of the plane in question from the surface. For the plane has only to support the weight above it; *i. e.*, every unit of area of the plane supports a prism, whose section is cos.a, and whose height is $\frac{y}{\cos.\ a}$.

2. The pressure on a vertical plane which cuts a horizontal line from the surface is parallel to the surface. For if we consider figure 1 to represent a section of the mass of earth along a line of steepest declivity, and $a\,b$ and $c\,d$ to be vertical planes, while $a\,c$ and $b\,d$ are parallel to the surface, then, inasmuch as the right prism of which $a\,c\,d\,b$ is a section must be in equilibrium, and the pressures on $a\,c$ and $b\,d$ are vertical and in equilibrium with the weight of the prism; it follows that the pressures on $a\,b$ and $c\,d$ must balance each other; hence, being both applied at the same distance from the surface, they must act in the same straight line parallel to the surface.

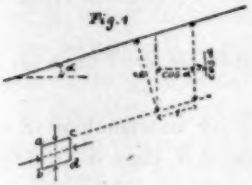
3. The shearing or tangential forces at any point on two planes at right angles to each other are equal in intensity. For if we consider an infinitely small rectangular parallepipedon, of which Fig. 2 represents a section, then by taking moments about 0 we shall have

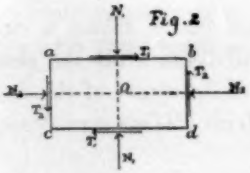
$$T_1.ab.ac = T_2.ac.ab \therefore T_1 = T_2,$$

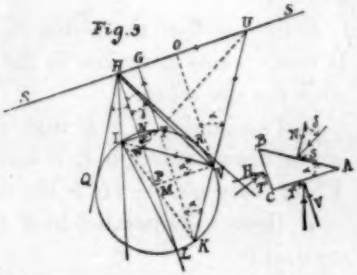
these being the intensities on the two planes.

Let us now consider an infinitely small triangular prism of a length perpendicular to the paper, equal to unity, and although all the other dimensions are infinitely small, let us take AC (Fig. 3) parallel to the surface and equal to 1, BC perpendicular to AC, and the angle $CAB = a$. For the areas of the sides of this prism we have

$$AC = 1; \quad BC = \tan.a; \quad BA = \sec.a.$$

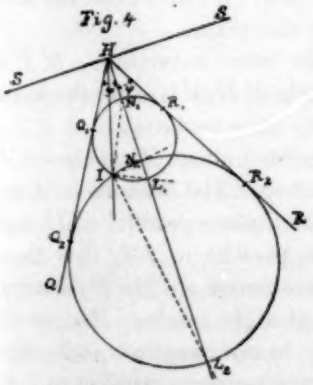


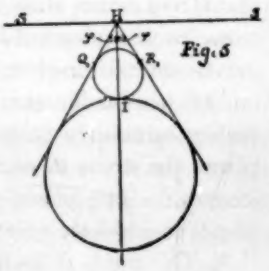




If we resolve the stresses on these sides normally and tangentially we have six forces acting on this prism, in the plane of the paper, as follows:

On AC: V and T.





On BC: H tan.a and T tan.a.

On AB: N sec.a and S sec.a. (See Fig. 3.)

These forces must be in equilibrium, and consequently they must form a closed polygon. Such a polygon is E, F, G, U, V, W, E, in

Fig. 3, in which $EF = T$; $FG = V$; $GU = H \tan.a$; $UV = N \sec.a$; $VW = S \sec.a$; $WE = T \tan.a$.

Supposing these forces to be laid down correctly, we can investigate some of their properties which will enable us to draw the figures.

1. E and G are in the same vertical line; GE is the intensity of the pressure on $AC = \gamma y$.

2. Produce GF and UV to K. Then $GK = GU.\cot.a = H \tan.a. \cot.a = H$.

3. Produce EF and WV to I. Then $EI = EW \cot.a = T \tan.a.\cot.a = T = EF$.

It follows that the points E, F, G, K and I are independent of a. If those points are given in the case of the plane AB, they will be the same for any other.

4. The angles IFK and IVK are each 90°. Hence a circle can be drawn through I, F and K, which will contain all the points V, for every plane; IK is the diameter, and M the centre of the circle.

5. Draw VO parallel to FG. Then $VO = VU \cos.a = N \sec.a. \cos.a = N$.

6. Draw VP parallel to EF, to meet EW produced. Then $VP = VW \cos.a = S \sec.a.\cos.a = S$.

7. It follows from the above that if once the circle IFK be drawn, then in order to find the intensity of the pressure on any plane AB, we have only to draw IV parallel to AB and VO and VP are the normal and tangential intensities of stress on this plane.

Draw $HEWPML$ and HI. The latter is vertical. HV is the intensity of the stress on AB; the angle PHV is δ, or the angle that stress makes with the normal to AB.

8. As the plane AB is changed, or rotated about A, the point V moves around the circumference of the circle. The intensity of stress on AB has for its maximum value HL, on a plane parallel to IL and for its minimum value HN, on a plane parallel to IN. On these planes the stress is normal; hence these stresses are the "principal stresses." The planes IL and IN are at right angles. Hence *the planes on which the principal stresses act are at right angles to each other.*

9. The angle δ has its maximum value for a plane parallel to IR, HR being tangent to the circle; as well as for a second plane parallel to IQ, HQ being also tangent to the circle.

10. The line WU is parallel to the actual pressure on the plane AB.

It is clear from the above that if once the circle is constructed, the

stress on any plane is easily found. It only remains to draw the circle.

This, however, we are unable to do in general, but we can locate it within limits. We know that the angle δ can never exceed the angle or friction φ, or angle of repose of the earth. Hence, if we draw from H two lines (Fig. 4) making angles φ on either side of HE, we know that the circle must be within those lines. Any circle through I, F, and K, which fulfills this condition is a possible circle of equilibrium, if we may so call a circle corresponding to a possible state of equilibrium of the mass of earth.

If the earth is just on the point of slipping, $\delta = \varphi$, and the circle is tangent to the two lines HR and HQ (Fig. 4). Two circles, $N_1 Q_1 L_1 R_1$ and $N_2 Q_2 L_2 R_2$ fulfill this condition, hence they represent the two limiting states of equilibrium when the earth is just ready to slip. It is with these cases only that the engineer has to deal. The larger

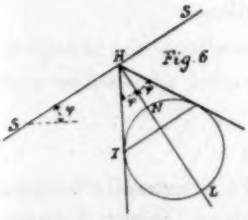


Fig. 6

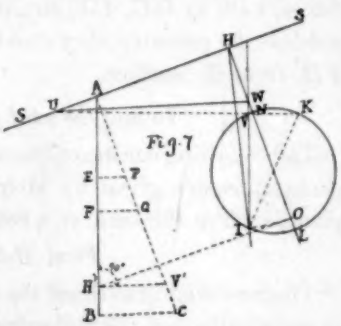


Fig. 7

circle represents the case where the maximum principal pressure HL (Fig. 3) is increased until the limiting condition is reached. This we may call the *passive* earth pressure; it occurs when a thrust or pressure, as of an arch or building, is exerted on the earth until it is just ready to give way. The smaller circle represents the case where the minimum principal pressure HN (Fig. 3) is decreased until the limiting condition is reached. This we may call the *active* earth pressure; it occurs when the thrust of a mass of earth is resisted, as by a retaining wall, and is, therefore, the most usual in the practice of the engineer. For the passive earth pressure the maximum pressure is HL_2 on a plane parallel to IL_2, and the minimum pressure HN_2 on a plane parallel to IN_2. For the active earth pressure the maximum pressure is HL_1, on a plane parallel to IL_1, and the minimum pressure HN_1 on a plane parallel to IN_1.

The maximum shear occurs on planes parallel to IR_2 and IQ_2 in the first case; IR_1 and IQ_1 in the second.

In the special case of a horizontal surface the force on AC is vertical, hence $EF = EI = o$, and the two circles are tangent. (Fig. 5). If the surface is inclined at the angle of repose φ, HQ is vertical, and coincides with HI, hence only a single condition of equilibrium is possible (Fig. 6).

In all the previous figures we have taken H in the line SS, which represents the surface. IH is the intensity of the pressure on a plane parallel to the surface, hence it equals γy. If the point considered is at a normal distance, IH, from the surface, then $y = IH$, and $\gamma y = \gamma . IH$. Hence IH represents a column of earth whose weight would produce the pressure really existing on a plane AC at a normal distance, IH, from the surface, and all the other lines in the figure which represent forces, such as GU, UV, etc., represent columns of earth which would produce the pressures they stand for, all for a point at a normal distance, IH, from the surface.

To find the total pressure on any plane.

The following constructions, which follow at once from the preceding paragraphs, are given by Mohr for finding the total pressure on any plane, such as the back of a retaining wall.

First Method. (Figure 7.)

The first step is to draw the circle ILK. This can easily be done geometrically, but the following method is simpler: Draw SS, representing the surface, and HL perpendicular to it at any point H, making HL any convenient distance, say 5 inches; make

$$HN = HL.\tan.^2\left(45° - \frac{\alpha}{2}\right)$$

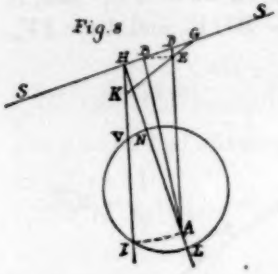
according to a formula yet to be explained. NL is the diameter of the circle. Draw HI vertically, the diameter IK, and a line IVW parallel to the wall: then draw KVU and UW, and the construction is complete. HV represents the intensity of the pressure at a point whose normal distance from the surface is $HI = HO$, and the pressure acts parallel to UW. No simpler construction could be desired. We have, then, if AB represents the wall, only to lay off HV at $H'V'$, perpendicular to AB, and knowing that the pressure is proportional to the depth below the surface, to draw the line $V'A$. The area of the triangle ACB, multiplied by γ, gives the pressure on the wall. If the

back of the wall is not plane, but composed of a number of planes, it is easy to find the pressure on each. Thus, in the above figure, the pressure on the part EF of the plane is represented by the area $EFPQ$. And finally, if the back is curved, we must divide it into a number of parts, and assume each to be plane. It is not necessary to go into farther details.

Second Method. (Figure 8.)

Draw the circle as before, and find first the pressure on a vertical plane. HV is the intensity of the pressure on such a plane at a point A, distant HI normally from the surface. If AD is the vertical plane the total pressure it supports is $\frac{\gamma . AD}{2} HV$, acting parallel to HD.

If we combine with this the weight of the triangle ABD, AB being



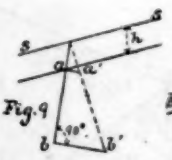


Fig. 9

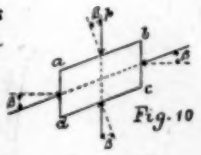


Fig. 10

the real wall, we shall have the pressure on the latter. The weight of $ABD = \frac{\gamma . AD}{2} BE$. We, therefore, lay off $HG = HV$, and $HK = BE$; and then the pressure on AB acts parallel to GK, and is equal to $\frac{\gamma . AD}{2} GK$.

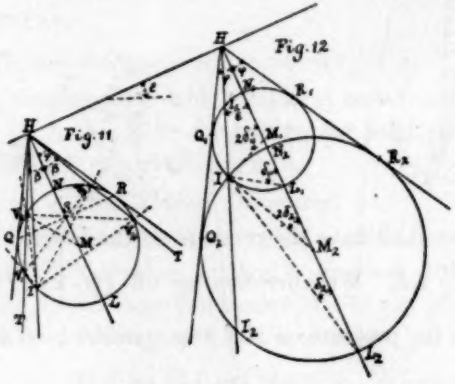
If the surface of the earth is loaded, reduce the load to the specific gravity of the earth, and let h be the height representing it (Fig. 9). The problem is, therefore, to find the pressure on a plane ab, as though the surface of the earth were $S'S'$. It will be represented by a trapezoid, $a\,a'\,b'\,b$.

That the pressure on a plane varies directly as the distance below the surface is easily seen when we remember that the pressure on a plane parallel to the surface follows that law, and that consequently the other pressures must do the some, inasmuch as Fig. 3 holds for any point, only the scale of forces changing. The resultant pressure

on a plane wall extending to the surface is, therefore, applied two-thirds of the distance from the top to the bottom.

Third Method. (Figure 10.)

This method depends upon the theorem of conjugate pressures; the pressure on a given plane ab having a certain direction, p, the pressure on a plane bc parallel to p is parallel to ab. (Fig. 10). The stresses on the four planes in Fig. 10 make, therefore, the same angle β with the normal. Now, if we draw (Fig. 11) the lines HT, HT', both making angles of β with HL, then the pressure on each of the four planes IV_1, IV_2, IV_3, IV_4, will make the angle β with the normal. The stress on IV_1 must be parallel to either IV_2, IV_3, or IV_4, and as the angle $V_1 IV_3 = V_1 V_4 V_3 = 90° - \beta$, it is clear that it must be parallel to IV_3, so that IV_1 and IV_3, as well as IV_2 and IV_4, are a pair of conjugate planes. To find the direction of the stress on IV_1, then, it is only necessary to lay off the angle $LHT' = LHV_1$, and draw IV_3.



But it so happens that if we draw $V_1 V_3$, crossing HL in S, we have the triangles HV_2M and HV_1S similar, and $HS : HV_1 :: HV_2 : HM$ $\therefore$ $HS = \frac{HV_1 . HV_2}{HM} = \frac{\overline{HQ}^2}{HM}$, so that S is the point when QR meets HL, and is, hence, independent of V_1. In order, then, to find the direction of the pressure on a plane IV_1, we need only to draw $V_1 S V_3$, and IV_3 is the required direction.

The preceding method will by its simplicity and accuracy commend itself to all. Founded on the condition of equilibrium of a particle of earth, it ought to give results agreeing with the analytical theory first

given by Rankine. The following equations, which the reader will easily demonstrate, will show the complete agreement of the two.

$$\sin.\varphi = \frac{N_{\max.} - N_{\min.}}{N_{\max.} + N_{\min.}} \tag{1}$$

$$\frac{1 - \sin.\varphi}{1 + \sin.\varphi} = \tan.^2\left(45° - \frac{\varphi}{2}\right) = \frac{N_{\min.}}{N_{\max.}} \tag{2}$$

Call δ the angle between the surface and the direction of $N_{\max.}$; then from the triangles HIM_1 and HIM_2. (Fig. 12.)

$$\frac{M_1 I}{M_1 H} = \sin.\varphi = \frac{\sin.\varepsilon}{\sin.(2\delta_1 + \varepsilon)} \tag{3}$$

$$\frac{M_2 I}{M_2 H} = \sin.\varphi = \frac{\sin.\varepsilon}{\sin.(2\delta_2 + \varepsilon)} \tag{4}$$

$$\sin.(2\delta + \varepsilon) = \frac{\sin.\varepsilon}{\sin.\varphi} \tag{5}$$

$$\sin.2\delta = \frac{\sin.\varepsilon}{\sin.\varphi}\left[\cos.\varepsilon \pm \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}\right] \tag{6}$$

Let y = normal distance from surface; then

$$HM_1 = \frac{1}{2}(N_{1\max.} + N_{1\min.}) = HI \cdot \frac{\sin.(2\delta_1 + \varepsilon)}{\sin.2\delta_1}$$

$$= y\frac{\sin.(2\delta_1 + \varepsilon)}{\sin.2\delta_1} \tag{7}$$

$$IM_1 = y\frac{\sin.\varepsilon}{\sin.2\delta_1} \tag{8}$$

$$HM_2 = y\frac{\sin.(2\delta_2 + \varepsilon)}{\sin.2\delta_2} \tag{9}$$

$$IM_2 = y\frac{\sin.\varepsilon}{\sin.2\delta_2} \tag{10}$$

From (5), $(2\delta_1 + \varepsilon) + (2\delta_2 + \varepsilon) = 180°$; $\delta_1 + \delta_2 = 90° - \varepsilon$ (11)

In (6), one of the signs of the double signs must apply to δ_1 and the other to δ_2; one cannot apply to both, for then we might have $\sin.2\delta_1 = \sin.2\delta_2$ or $\delta_1 + \delta_2 = 90°$, which is contradictory of (11). We have, then,

$$N_{1\max.} = \gamma.HL_1 = \gamma.(HM_1 + IM_1) = \gamma y.\left[\frac{\sin.(2\delta_1+\varepsilon)}{\sin.2\delta_1} + \frac{\sin.\varepsilon}{\sin.2\delta_1}\right]$$

$$= \gamma y\frac{1+\sin.\varphi}{\cos.\varepsilon + \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}.$$

$$= \gamma y \frac{\cos.\varepsilon - \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}{1 - \sin.\varphi} \tag{12}$$

Similarly,

$$N_{1\min.} = \gamma y \frac{1 - \sin.\varphi}{\cos.\varepsilon + \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}} =$$

$$\gamma y \frac{\cos.\varepsilon - \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}{1 + \sin.\varphi} \tag{13}$$

$$N_{2\max.} = \gamma y \frac{1 + \sin.\varphi}{\cos.\varepsilon - \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}$$

$$= \gamma y \frac{\cos.\varepsilon + \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}{1 - \sin.\varphi} \tag{14}$$

$$N_{2\min.} = \gamma y \frac{1 - \sin.\varphi}{\cos.\varepsilon - \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}$$

$$= \gamma y \frac{\cos.\varepsilon + \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}{1 + \sin.\varphi} \tag{15}$$

The intensity of the pressure on a vertical plane is represented for the passive state by $H I_2 = p_2$, and for the active state by $H I_1 = p_1$, and we have

$$p_1 . H I = p_1 . \gamma . y = \overline{Q_1 H^2} = N_{1\max.} N_{1\min.}$$

$$= \gamma^2 y^2 . \frac{\cos.\varepsilon - \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}{\cos.\varepsilon + \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}, \text{ hence}$$

$$p_1 = \gamma y \frac{\cos.\varepsilon - \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}{\cos.\varepsilon + \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}} \tag{16}$$

Similarly,

$$p_2 = \gamma y \frac{\cos.\varepsilon + \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}}{\cos.\varepsilon - \sqrt{\cos.^2\varepsilon - \cos.^2\varphi}} \tag{17}$$

These equations show the complete agreement of the two methods.

Mohr has shown how the influence of the cohesion of the earth may be taken into account, but as this has little practical importance it is not necessary to do more than allude to it.

Finally, a few words regarding the limits within which the theory or method is applicable. We have assumed a plane upper surface. For this case our results are absolutely exact, but if the top surface is not plane, it is generally conceded that an exact solution of the problem of finding the pressure on any plane is impossible. But even

with a plane upper surface, we have seen that on any plane except one parallel to the surface, there are various pressures which are compatible with equilibrium. We have shown how to find the pressures for the two limiting conditions, when the earth is just ready to slide; or, in other words, we have found for any plane the least and greatest pressures consistent with equilibrium. In applying the method, then, it is only necessary to be sure that we know just what case we have to do with. In the case of a retaining wall we wish to find how it must be proportioned in order to prevent the mass of earth from sliding, *i. e.*, we wish to find the least pressure which would hold the earth in equilibrium, and make our wall so that the pressure will not displace it. Now, although by the method given we can find the least pressure on any plane in an unlimited mass of earth, yet it is not on every plane that we can replace the pressures by the resistance of a wall. Suppose, for instance, we made a wall parallel to the surface, removing the earth above; this is entirely without meaning, for then there would be no earth above that plane, and the earth would stand without the wall. Other positions can readily be imagined, in which a wall could be placed without experiencing the pressure which would act on that plane in an unlimited mass of earth. The following limitation, given by Mohr, will now be readily seen to be reasonable:

"A mass of earth supported by a wall is in the active condition as regards pressure, or at the lower limit of equilibrium, and in order to determine the pressure on the wall, the theory of earth pressure in an unlimited mass of earth may be applied, provided that the straight line, which, according to that theory, gives the direction of the maximum principal stress, at the foot of the wall, lies within the mass of earth." In other cases, as, for instance, where the earth slopes downward from the wall, Mohr advocates the use of the old theory, so ably discussed in these pages not long ago by Prof. Du Bois, the pressure, however, being assumed perpendicular to the wall. Such cases, however, will not often occur in the practice of the engineer. In cases where the surface of the earth is not plane, the method can be used, and probably is as correct as any other, if the real surface be replaced by a plane. The engineer will readily see in each particular case how such a plane can best be assumed.

THE PLATINUM-WATER PYROMETER.

By J. C. Hoadley.

The following description of the apparatus used for the determination of high temperatures, up nearly to the melting-point of platinum, is offered in answer to several inquiries on the subject.

The object to be attained is a convenient and reasonably accurate application of the method of mixtures to the determination of temperatures above the range of mercurial thermometers, say 500°F., up to any point not above the melting-point of the most refractory metal available for the purpose, platinum.

A first requisite is a cup or vessel of convenient form, capable of holding a suitable quantity of water, say about two pounds avoidupois. Berthelot decidedly prefers a simple can of platinum, very thin, with a light cover of the same metal, to be fastened on by a bayonet hitch. For strictly laboratory work, this may be the best form; but for the hasty manipulation and rough usage of practical boiler testing something more robust, but, if possible, equally sensitive, is required. The vessel I have used is represented in section in the accompanying cut, Fig. 1.

The inner cell, or true containing vessel, is 4·25 inches in diameter, and of the same height on the side, with a bottom in the form of a spherical segment, of 4·25 inches radius. It is formed of sheet brass 0·01 inch thick, nickel-plated and polished outside and inside. The outer case is 8 inches diameter and 8·5 inches deep, of 16-ounce copper, nickel-plated and polished inside, but plain outside. There are two handles on opposite sides, for convenience of rapid manipulation. The top, of the same copper as the sides and bottom, is depressed conically, like a hopper, and wired at its outer edge, forming a lip all around for pouring out of. The central cell is connected with the outer case only by three rings of hard rubber (vulcanite), each 0·25 inch thick, the middle ring completely insulating the cell from its continuation upward, and from the outer case. A narrow flange is turned outward at the upper edge of the cell, and a similar flange is also turned outward at the lower edge of the cylindrical continuation of the walls of the cell upward. Between these two flanges, the

middle ring of hard rubber is interposed, and the two parts, the cell and its upward continuation, are clamped together by the upper and lower rings of hard rubber, which embrace the flanges and are held together by screws. The joints between the flanges and the middle ring of hard rubber, which might otherwise leak a little, are made tight with asphaltum varnish.

Fig. 1 shows two partitions, dividing the space between the cell and the case into three compartments, and a concave false bottom. The cover is also seen to be divided into three compartments, by two partitions, and each compartment of the vessel and of its cover is provided with a small tube for inserting a thermometer. This construction was adopted in the first instruments made, for the purpose

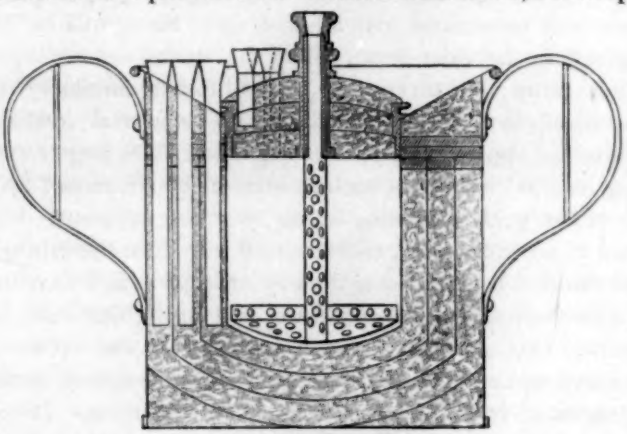


Fig. 1.

of observing the rate of heat transmission through the successive compartments, but these parts are without importance with respect to the practical use of the instrument, and may as well be omitted, as they considerably increase the cost, being nickel-plated and polished on both sides. The top and bottom plates of the cover are of 0·01 inch brass, nickel-plated and polished on both sides, both convex outward, the bottom plate but slightly, the top plate to 4·25 inches radius. A ring of hard rubber connects, yet separates and insulates these plates, and they are bound together with the ring into a firm structure by a tube of hard rubber, having a shoulder and knob at the top, and at the lower end a screw-thread engaging with a thin nut soldered to the upper-side of the bottom plate. When the cover is in place, its lower plate is even with the top of the cell; and the

contained water, which nearly fills the cell, is surrounded by polished, nickel-plated, brass-plates 0·01 inch thick, insulated from other metal by interposed hard rubber. The spaces between the cell and case (a single space if the partitions are omitted), the space above the hard rubber rings and the space or spaces in the cover are all filled with eider-down, which costs $1.00 per ounce avoidupois, but a few ounces are sufficient. Soft, fine shavings, or turnings of hard rubber are said to be excellent as a substitute for eider-down. Heat cannot be confined by any known method. Its transmission can be in some degree retarded, and in a greater degree, perhaps, regulated. Some heat will be promptly absorbed by the sides, bottom, and cover of the cell, and by the agitator; but this does no harm, as its quantity can be accurately ascertained and allowed for. Some will be gradually transmitted to the eider-down, filling the spaces, and through this to the outer casing; but this can be reduced to a minimum by rapid and skillful manipulation, and its quantity, under normal conditions, can be ascertained approximately, so as not to introduce large errors. But varying external influences, such as currents of air, caused by opening doors, or by persons passing along near the apparatus during the progress of an experiment, which would introduce disturbing irregularities, can best be guarded against by such spaces as I have described, filled with the poorest heat-conductor and the lightest *solid* substance attainable. Air, although a poor heat-conductor, and extremely light, is diathermous, and offers no obstruction to the escape of radiant heat.

The agitator is an important part of the apparatus. Its object, in this instrument, is two-fold. *First*, it serves to produce a uniform temperature throughout the body of water in the instrument; and *secondly*, it answers as a support to the heat-carrier of platinum or other metal, often intensely hot, which would injure or destroy the delicate metal of the bottom if allowed to fall on it. For this second purpose, no spiral revolving agitator, such as that commended by Berthelot, would suffice. The best form is such as I have shown in Fig. 1. A concave disc of sheet-brass, made to conform to the shape of the bottom of the cell, with a narrow rim turned up all around, of about 0·02 inch thickness, is liberally perforated with holes to lighten it, and to give free passage to water. The concave form causes the streams of water, produced by slightly raising and lowering the agitator, to take a radial direction downward or upward, so as to cross each other and promote rapid mixing. By a slight modification

small vanes might be turned outward from the surface of the metal, which would produce mixing currents if the agitator were given a slight reciprocatory revolving motion, thus avoiding the alternate withdrawal and re-immersion of any part of the stem so strongly deprecated by Berthelot; but for several reasons I think an up and down motion of the agitator desirable in this instrument. The platinum heat-carrier, sometimes at a temperature of 2500° to 2800°F., is thereby brought into more rapid and forcible contact with the water, steam or water in the spherical condition is washed away from its surface, and by cooling it more rapidly, the duration of the observation is lessened, and errors due to transmission of heat through the walls of the instrument are diminished. The upper part of the agitator stem is of hard rubber, and the brass portion, which terminates at the under side of the cover when the agitator is in its lowest position, suspended by the shoulder at the upper end, need never be lifted for the purpose of mixing out of the hard rubber tube at the cover, so that loss of heat from this cause must be very slight. The brass tube is very freely perforated with holes to admit water, streaming radially through the holes in the agitator, to contact with the thermometer. The hole in the stem at the top is flared, to receive a cork, through which the thermometer is to be passed. The bulb of the thermometer should be elongated, and very slightly smaller in diameter than the stem. After passing it through the cork, a very slight band—a mere thread—of elastic rubber should be put around the bulb, near its lower end, or a thin, narrow shaving of cork may be wound around and tied on, to keep it from contact with the brass tube, for safety; and a little tuft of wool, curled hair, or hard rubber shavings should be put in the bottom of the brass tube to avoid accidents. For the same purpose, a light, but sufficient fender of brass wire, say 0·03 inches diameter, might be judiciously placed around the brass tube at a little distance, to protect it and the thermometer inside of it from shocks from the platinum ball when hastily thrown in, as it must always be. I have had delicate and costly thermometers broken for want of such a fender. Thermometers cannot be too nice for this work. For accurate work at moderate temperatures, they should be about 14 inches long, having a "safe" bulb at the upper end, with a range of 20°F.—32° to 52°—in a length of 10 inches, giving half an inch to a degree F., and carefully graduated to tenths of a degree, so that they can be read to hundredths, corresponding to single degrees of the heat-carrier in the normal use of the instrument.

For the determination of the highest temperatures, up closely to 2900°F., it will be convenient to have thermometers of greater range, say 32° to 82°F., 50° in a length of 12·5 inches, or a quarter of an inch to a degree F., also graduated to tenths, or at the least, to fifths of a degree. Such thermometers will be about 17 inches long.

It is very satisfactory to have *two* instruments and a good outfit of thermometers and heat-carriers, in order to take duplicate observations for mutual verification and detection of errors.

Heat Carriers.

For these platinum is greatly to be preferred to any other known substance. Its rather high cost is the only objection to its use. Its heat capacity is low, by weight, but its specific gravity is great, and sufficient capacity can be obtained in moderate bulk, while its high conductivity tends to shorten the duration of each experiment or observation. A convenient outfit for each instrument consists of three balls, hammered to a spherical form, one 1·1385 inches diameter, weighing 4200 grains, = 0·6 pounds avoirdupois; one 0·9945 inch diameter, weighing 2800 grains, = 0·4 pounds; and one 0·7894 inch diameter, weighing 1400 grains, = 0·2 pounds.

These can be obtained at $1\frac{3}{4}$ cents per grain, and will cost, respectively, $70.00, $46.67, and $23.33, and collectively, $140.00. At the assumed specific heat of Pt = 0·0333, the heat capacity of the respective balls will be $\frac{1}{100}$, $\frac{1}{150}$ and $\frac{1}{300}$ of 2 pounds of cold water, and the two smaller balls used together will be equal to the larger one. Corrections for varying specific heat of platinum may be conveniently made by the tables given in a previous article.* Corrections for varying specific heat of water are less important, but may be made by the following table:

A composite heat-carrier, of iron covered with platinum, answers well for temperatures up to about 1500°F. A ball of wrought iron 0·88 inch diameter will weigh 700 grains, and a capsule of platinum spun over it 0·048 inch thick, making the outside diameter 0·976 inch, will also weigh 700 grains. Upon the assumption of 0·0333 for the specific heat of Pt and 0·1666 for that of Fe, the composite ball will have a heat capacity equal to that of 4200 grains of Pt, and equal to 0·01 of that of 2 pounds of cold water. A patch, about 0·35

* Journal for August, pp. 97, 98, and errata in Journal for September, p. 172.

Temperatures, Fahrenheit, and Corresponding Number of British Thermal Units Contained in Water from Zero Fahrenheit.

Deg	B. t. u.	Deg.	B. t. u.	Deg.	B. t. u.	Deg.	B. t. u.
32	32·000	57	57·007	82	82·039	107	107·101
33	33·000	58	58·007	83	83·041	108	108·104
34	34·000	59	59·008	84	84·043	109	109·107
35	35·000	60	60·009	85	85·045	110	110·110
36	36·000	61	61·010	86	86·047	111	111·113
37	37·000	62	62·011	87	87·049	112	112·117
38	38·000	63	63·012	88	88·051	113	113·121
39	39·001	64	64·013	89	89·053	114	114·125
40	40·001	65	65·014	90	90·055	115	115·129
41	41·001	66	66·015	91	91·057	116	116·133
42	42·001	67	67·016	92	92·059	117	117·137
43	43·001	68	68·018	93	93·061	118	118·141
44	44·002	69	69·019	94	94·063	119	119·145
45	45·002	70	70·020	95	95·065	120	120·149
46	46·002	71	71·021	96	96·068	121	121·153
47	47·002	72	72·023	97	97·071	122	122·157
48	48·003	73	73·024	98	98·074	123	123·161
49	49·003	74	74·036	99	99·077	124	124·165
50	50·003	75	75·027	100	100·080	125	125·169
51	51·004	76	76·029	101	101·083	126	126·173
52	52·004	77	77·030	102	102·086	127	127·177
53	53·005	78	78·032	103	103·089	128	128·182
54	54·005	79	79·034	104	104·092	129	129·187
55	55·006	80	80·036	105	105·095	130	130·192
56	56·006	81	81·037	106	106·098	131	131·197

inch diameter, has to be put in to close the orifice where the Pt capsule is spun together, and a slight stain will show itself at the joint around this patch, from oxidation of the iron, but the latter will be pretty effectually protected. Difference of expansion, which will not exceed ·007 inch in diameter, will not endanger the capsule of Pt. The interruption of conductivity at the surface contact of the two metals makes the process of heating and cooling a little slower, but not noticeably so.

Such composite balls can be obtained for $20 each, $50 less than the cost of an equivalent ball of solid platinum, which is preferable in all but cost. Iron balls could be used for a few crude determinations. Cast iron varies too much in composition, and wrought iron oxidizes rapidly. While the oxide adheres it gains in weight, and when scales fall off it loses; and the specific heat of the oxide differs from that of metallic iron. Whatever metal is used, care must be taken to apply the appropriate tabular correction for Pt, Fe, or Pt, and Fe.

Manipulation.

Small graphite crucibles with covers, as shown in section in Fig. 2, serve to guard against losing the ball, to handle it by when hot, and to protect it against loss of heat during transmission from the fire to the pyrometer. To guard against overturning the crucibles, moulded

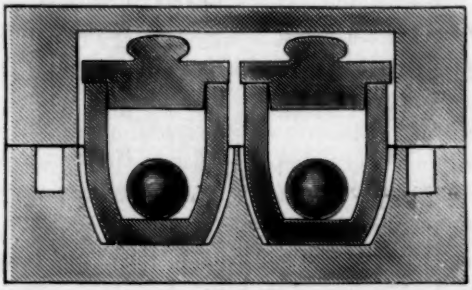


Fig. 2.

fire-brick should be provided to receive them,—two crucibles being put into one brick, in the same exposure, whenever great accuracy is desired, each serving as a check on the other, and their mean being likely to be more nearly correct than either one if they differ. The fire-brick cover is occasionally useful to retard cooling if, by reason of local obstructions, some little delay is unavoidable in transferring the

balls from the fire to the water of the pyrometer. With convenient arrangements this may be done in three seconds. After observing the temperature of the water, make ready for the immersion of the heat-carrier by raising the agitator until a space of only about 1·5 inch is left between its rim and the cover. An instant before putting in the heat-carrier—"pouring" it in from the crucible—lift the cover and agitator both together, so that the rim of the latter is level with the sloping top of the instrument. The agitator then receives the hot ball without shock, and no harm is done. If the ball goes below the agitator it is likely to injure the bottom of the cup. If, on taking the temperature of the water before the immersion of the heat-carrier, any change is observed, either rising or falling, the direction and rate of such change, and the exact interval of time between the last recorded observation and the immersion should be noted, in order to determine the exact temperature of the water at the instant of immersion. The temperature of the water will continue to rise as long as the heat-carrier gives out heat faster than the cell loses it. The rise will grow gradually slower until it ceases, and the maximum can be very accurately determined. Examples of the mode of using the tables, and of determining the true temperature of the heat-carrier at the instant of immersion from the observations with the instrument, are given in the table on pages 170 and 171 of this journal for September. A method of using the tables by which a closer approximation to the true temperature may be reached, will be pointed out in a subsequent article.

DETERMINATION OF THE CALORIFIC CAPACITY OF THE METALS OF THE PYROMETER, in terms of water, *i.e.*, in British thermal units.

First. Weigh the cup, or cell, the lower plate of the cover and the metallic portion of the agitator, and compute their heat-capacity by the specific heat of the respective metals. Compute also the heat-capacity of the thermometer; or, if it be long, of so much of it as is found to share nearly the temperature of the immersed portion. The result will be a minimum,—indeed, in so small a vessel the inevitable loss by conduction and radiation will amount to more than one-third as much as the simple heat-capacity of the metals.* The total must be ascertained by an application of the method of mixture. Ascertain the temperature of the interior of the instrument simply; pour in

* In our case the heat-capacity, thermometer included, was ·0757; total, ·1053; radiation, etc., ·0296. Respectively, 71·9 per cent. and 28·1 per cent. of the total.

quickly but carefully a known quantity of water, say about 2 pounds, of known temperature, say about 100°F., and ascertain the temperature as soon after pouring as mixing can be properly performed. But a correction is necessary for loss of heat in the act of pouring. To ascertain the amount of this correction prepare a bath of tepid water, and bring all parts of the instrument—outside, inside and interior portions, together with the vessel to pour from—exactly to one common, carefully ascertained temperature. Now take 2 pounds of the water and pour it into the cell in the same manner as before. Exposure of so thin a stream on two surfaces to the air of the room will produce a certain degree of refrigeration in the water, which is supposed to be warmer than the air, say at about 160°F. This effect will be due to conduction, by contact with the air, to radiation, and to evaporation; and by so much the refrigeration observed in mixing is to be diminished.

Four experiments, carefully conducted, gave the following results:

Loss of temperature by pouring at 170°F., 0·81°, 0·86°, 1·00°, and 1·07°F.; mean, 0·935°F.

The following are values of the calorific capacity of my pyrometers, that is, of those parts of each which share directly the temperature of the inclosed water, including the thermometer to be used with the instrument, and the heat communicated to the eider-down and otherwise lost during an observation, expressed in decimals of a British thermal unit, or in decimals of a pound of cold water:

0·1048, 0·1052, 0·1077, 0·1008, 0·1028, and ·01104.

Mean,	0·1053	= 0	lb.	1 oz.	11	drms.
Add water,	1·8947	= 1	"	14 "	5	"
	2·0000	= 2	"	0 "	0	"

This was the value used. The instrument, being put on delicate coin scales and counterbalanced, weights equal to 1·8947 lbs. avoirdupois = 1 lb. 14 oz. 5 drms. were added to the counterbalancing weights, and cold water was poured in until the scales again balanced.

The pyrometer with its contained water was then just equal in heat-capacity, while the temperature was not above 38°F. to 2 pounds of cold water. The two instruments were sensibly alike, but were numbered No. 1 and No. 2, and at each observation the one used was noted.

The process of preparation and testing appears long and tedious, and

is indeed somewhat so; but the instruments once well made are durable, convenient in use, and with care reasonably accurate.

Compared with mercurial thermometers between 212° and 600°F., I believe them to be much more accurate, although less convenient.

For a range of temperatures from 212° to 900°F. they are certainly more trustworthy than anything save an air thermometer of suitable construction; and for all temperatures from 800° or 900° F. up nearly to the melting point of platinum they are without a rival, so far I know.

For some situations the ball can best be inserted in the fire or other situation where an observation is desired, and withdrawn for immersion by means of long, slender tongs, with jaws resembling bullet-moulds.

A word about the melting point of platinum. My balls certainly began to melt below 2950°F., but I am by no means sure that they do not contain any silver, although their specific gravity gives assurance that are at least nearly pure.

EXPERIMENTS ON THE FATIGUE OF SMALL SPRUCE BEAMS.

By F. E. KIDDER, B.C.E.

[Presented to the American Academy of Arts and Sciences by Prof. Chas R. Cross, May 10, 1882.

The following experiments were undertaken with the object of determining, if possible, what part of the so-called breaking load of a beam would ultimately cause the beam to break, all the conditions being the most favorable.

Incidental to the experiments the modulii of rupture and of elasticity of small beams of kiln-dried spruce were determined.

The experiments were made in the physical laboratory of the Massachusetts Institute of Technology, the testing machine used being the same as that described in a paper presented to the society, February 9, 1881, [also published in the JOURNAL OF THE FRANKLIN INSTITUTE, April, 1881]. With this machine the loads are applied by suspending known weights directly from the centre of the beam. The deflections of the beams were measured by means of a micrometer screw, the principle

of electrical contact being taken advantage of in reading it. Although the micrometer screw used was graduated so as to read to $\frac{1}{10000}$ of an inch, the writer doubted reliability beyond $\frac{1}{1000}$ of an inch, and the modulii given have been computed from deflections measured only to thousandths of an inch.

As the load was suspended from a bolt resting upon the beam at the centre, it was necessary to measure the deflections one inch from the centre. For the small deflections from which the modulii of elasticity were determined the difference between the measured deflection and the actual deflection is so small that it would not come within the limit to which the deflection was measured. For the deflections given in the tables the deflection at the centre would be somewhat larger, but the error does not practically affect the results.

As the room in which these experiments were made is kept very warm and dry, any unseasoned timber would be so affected by the heat that it would be impossible to tell whether the deflections were caused entirely by the load, or partly by the heat in the room; hence it was thought best in making these experiments to use kiln dried lumber.

The small beams upon which the experiments were made were taken from two spruce plank, selected from lumber which had been cut in Maine the previous season. The plank were kept in a drying kiln three weeks, and were then cut up into pieces about two inches square, and allowed to dry in the laboratory until tested.

For convenience the beams cut from one plank are classed as series No. 2, and those from the other as Series No. 3. Series No. 1 including those beams previously experimented upon, and which were discussed in my previous paper.

All of the pieces of wood experimented upon were what might almost be called perfect pieces, being straight grained and free from knots. They were about $1\frac{1}{2}$ inches square, and 40 inches between supports. The exact dimensions with other data being shown in the tables. Tables I, II and III are so arranged that a comparison of the strength and stiffness, together with the ultimate deflection of pieces in the different series can easily be made.

The letter E is used to denote the modulus of elasticity in these tables, and R the modulus of rupture. The quantity denoted by A is one-eighteenth of the modulus of rupture.

It will be noted that the pieces in Series No. 1, were not kiln-dried, but were taken from a plank, selected from ordinary lumber.

TABLE NO. I.

SERIES NO. 1.—*Unseasoned Spruce.*

No. of test piece	Clear span. *l.*	Breadth. *B.*	Depth. *D.*	*E.*	*R.*	Centre breaking w't for beam 1″×1″. *A.*	Deflection just before breaking.
	ins.	ins.	ins.	lbs.	lbs.	lbs.	ins.
1	40	1·475	1·45	1,731,000	11,380	632	1·565
2	40	1·445	1.52	1,556,000	10,330	574	1·394
3	40	1·469	1·448	1,765,000	10,710	595	1·48*
4	40	1·42	1·498	1,736,000	10,830	601	1·466
5	40	1·45	1·485	1,688,000	11,980	665	1·579
6	40	1·48	1·44	1,795,000	11,040	613	.....
7	40	1·464	1·46	1,682,000	10,570	587	.....
8	40	1·42	1·48	1,647,000	11,280	626	1·571
9	40	1·46	1·46	1,704,000	11,180	621	1·425
10	40	1·441	1.46	1,616,000	12,440	691	1·81*

*Approximately.

Average value of *E*, 1,692,000 lbs.

Average value of *R*, 12,170 lbs.; of *A*, 620 lbs.

SERIES NO. 2.

In commencing this series of experiments five of the beams were subjected to loads of 30 and 40 lbs., and the deflection measured at the end of one hour from the time the load was applied. From these deflections the modulii of elasticity have been calculated. The values

given in Table II are the average of the values obtained from the deflection under 30 lbs. and the deflection under 40 lbs.

Having determined the modulii of elasticity of these pieces, five pieces of the series were broken by means of a gradually increasing load, and from their breaking load the modulus of rupture of each

TABLE II.

SERIES No. 2.—*Kiln-dried Spruce.*

No. of test piece.	Clear span. *l.*	Breadth. *B.*	Depth. *D.*	*E.*	Deflection just before breaking.	*R.*	Centre breaking w't for beam. 1″×1″. *A.*
	ins.	ins.	ins.	lbs.	ins.	lbs.	lbs.
1	40	1·52	1·52	1,573,800	1·676	12,560	698
2	40	1·495	1·50	....	1·656	13,590	755
3	40	1·520	1·50	....	1·517	12,540	697
4	40	1·51	1·503	....	1·816	13,720	762
5	40	1·506	1·506	....	1·662	13,740	763
6	40	1·51	1·516	1,760,000	1·937	broke under ¾ B. W.	
7	40	1·508	1·508	1,636,000	1·79	" " ¾ B. W.	
8	40	1·510	1·518	1,721,000	.....	car'd ¾ B.W. 22 d'ys.	
9	40	1·50	1·504	1,580,000	.....	tested with ½ B. W.	

Average value of *E* for five pieces, 1,654,000 lbs.
Average value of *R* for five pieces, 13,230 lbs.
Average value of *A* for five pieces, 735 lbs.

piece was computed. The average value of these five pieces (Nos. 1–5) was then considered to be the average value for the whole series, and the breaking weights of the remaining pieces of the series were computed on this basis.

Before attempting to break the remaining pieces, a load of 50

lbs. about $\frac{1}{15}$ of its breaking load, was applied to Piece No. 6, with the object of determining if the deflection under this slight load would continually increase. The load was kept on the beam 288 hours, and the deflections, taken at intervals, are given in Table IV. The

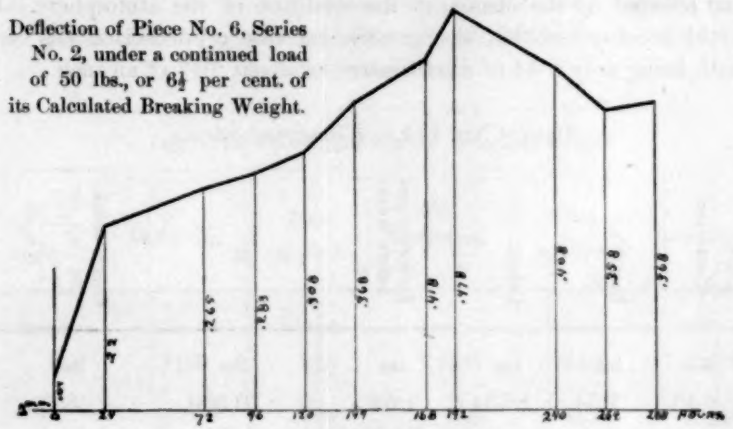


PLATE I.

increase in the deflection is also shown graphically by the diagram in Plate I. From these it will be seen that the deflection increased very rapidly for the first 24 hours, and then quite regularly, but slowly, for

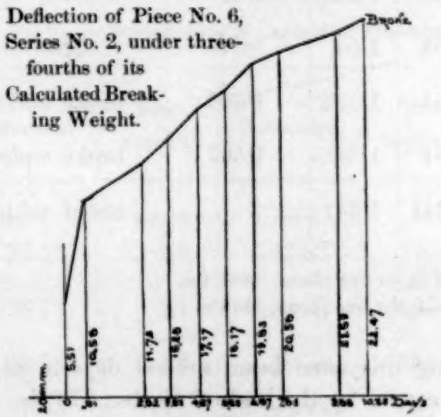


PLATE II.

192 hours, and after that it continued to *decrease* for 72 hours, when it slightly increased again. As it was desired to use the machine for the more direct purposes of the experiments, the piece was removed

from the machine, but it would have been interesting to have watched the further action of the load on the beam.

During the time that the deflections *decreased* the weather was very wet, and it is the opinion of the writer that the deflections were somewhat affected by the change in the condition of the atmosphere. It should be observed that the greatest increase of deflection was very small, being only 0·44 of a millimetre, or about ·017 of an inch.

TABLE NO. III.—*Kiln-dried Spruce.*

No. of test piece.	Clear span. *l*	Breadth. *B.*	Depth. *D.*	Deflection just before breaking.	*R.*	Centre breaking w't for beam 1″×1″×1. *A.*
	ins.	ins.	ins.	ins.	lbs.	lbs.
1	40	1·54	1·534	1·59	10,500	583
2	40	1·54	1·54	1·654	10,596	588
3	40	1·545	1·54	1.638	10,644	591
4	40	1·54	1·545	1·42	8,487	471
5	40	1·54	1·54	1·575	9,200	511
6	40	1·54	1·532	1·607	broke under ¾ B. W.	
7	40	1·54	1·54	1·567	broke under ⅞ B. W.	
8	40	1·541	1.541	....	tested with ½ B. W.	

Average value of *R*, for five pieces, 9,885 lbs.
Average value of *A*, for five pieces, 549 lbs.

After allowing this same beam several days in which to recover from the strain caused by the load of 50 lbs., 574 lbs. or ⅔ of its calculated breaking load was suspended from the beam and the deflection measured at frequent intervals, with the results shown in Table IV. After carrying the load 260 hours the beam broke. The dia-

gram on Plate 2 gives a graphical representation of the increase of the deflection.

Piece No. 7 of this series was computed to hold 756 lbs. before breaking, and 504 lbs. or $\frac{2}{3}$ of the breaking weight was suspended

TABLE IV.—*Deflections of Piece No. 6, Series No. 2, under a Continued Load.*

Load of 50 lbs.—6½ per cent. of Breaking Weight.

Time applied.	Deflection.	Time applied.	Deflection.	Time applied.	Deflection.
hours.	mm.	hours.	mm.	hours.	mm.
0	2·04	120	2·308	240	2·408
24	2·22	144	2·368	264	2·358
72	2·265	168	2·418	288	2·368
96	2·283	192	2·478	load removed.	

Load of 574 lbs. or three-fourths of Calculated Breaking Weight.

Time applied.	Deflection.	Time applied.	Deflection.	Time applied.	Deflection.
hours.	mm.	hours.	mm.	hours.	mm.
0	25·51	69	33·83	140	38·17
1·5	28·72	75	34·33	165	39·83
4·5	30·58	92	35·28	188	40·58
1·95	31·72	117	37·17	237	41·59
				260*	42·47

* Broke shortly after.

from the beam. After supporting this load 134 hours the beam broke. The deflections of the beam, measured at frequent intervals, are given in Table V.

TABLE V.—*Deflection of Piece No. 7, Series No. 2, under 504 lbs., or two-thirds of its Calculated Breaking Weight.*

Time applied.	Deflection.	Time applied.	Deflection	Time applied.	Deflection.
hours.	mm.	hours.	mm.	hours.	mm.
0	23·04	48	34·43	110	41·64
14	28·48	86	38·06	120	43·16
24	31·26	96	40·04	134	45·46
38	33·16	....	....	broke soon after.	

Piece No. 8 of this series carried two-thirds of its breaking weight 499 hours, with an increase in deflection of 7·64 millimetres (·3 inch). As the deflection was constantly increasing, and was already more than the deflection of Piece No. 7 when the load was first applied, it seems to the writer that the beam would undoubtedly in time have been broken by its load. The deflection of this beam is given in Table VI.

The last piece in Series No. 2, Piece No. 9, was subjected to a load of one-half of its breaking weight for 327 hours, during which time the deflection constantly increased from 16·39 mm. (0·644 in.) to 19·07 mm. (0·75 in.). The load was then removed and the "set" of the beam measured. This set gradually decreased as the beam recovered itself, until it was quite small, and probably the larger part of it was due to the indentation of the beam at the points of support, something which cannot well be prevented in a wooden beam.

After 21 days rest, the beam was put in the machine and the same load of 374 lbs., or one-half the breaking load, was alternately applied and taken off with the results shown in the last part of Table VII. It will be seen from this table that each time the load was applied the beam deflected a little more than at the previous application of

the load; also, that the set increased much faster than the deflection. This tends to prove that the continued application and removal of one-half the breaking weight of a beam will in a comparatively short time cause it to break.

TABLE VI.—*Deflection of Piece No. 8, Series No. 2, under 511 lbs. or two-thirds of its Calculated Breaking Weight.*

Time applied.	Deflection.	Time applied.	Deflection.	Time applied.	Deflection.
hours.	mm.	hours.	mm.	hours.	mm.
0	21·98	211	26·86	379	29·02
44	23·09	235	27·09	403	49·15
68	25·45	259	27·82	427	29·37
92	25·78	283	28·14	451	29·48
116	25·94	308	28·53	475	29·53
140	26·20	332	28·81	499	29·62
168	26·43	....	....	weight taken off.	

SERIES No. 3.

The results of the second series of experiments convinced the writer that a perfect, dry spruce beam would in time break under a load of only one-half of its calculated breaking weight, but to make the results more certain, a third series was undertaken, with the same object in view. The pieces of wood tested in this series were to all appearances equally as perfect (and they must have been as dry) as those in Series No. 2.

Table III gives the dimensions of the beams in this series, the modulii of rupture of the first five pieces and the ultimate deflection of all of the pieces.

The average value of the modulii of rupture of the five pieces was

taken as the basis from which the breaking weight of pieces No. 6, 7 and 8 were computed.

Piece No. 6 of this series was broken by a load of three-fourths of its calculated breaking weight 22 days after the load was applied. The deflections of this beam at various intervals during the 22 days are given in Table VIII, and the increase in the deflection is shown graphically by the diagram on Plate 3.

TABLE VII.—*Experiments on Piece No. 9, Series No. 2.*

Deflection under 374 lbs., or one-half of its Calculated Breaking Weight.

Time applied.	Deflection.	Time applied.	Deflection.	Time applied.	Deflection.
hours	mm.	hours.	mm.	hours.	mm.
0	16·39	48	17·96	211	18·74
2	17·08	66	18·08	234	18·87
18	17·49	116	18·17	279	18·91
25	17·77	138	18·34	303	19·01
42	17·865	164	18·43	327*	19·07

*Load removed.

Recovery of the piece on removal of the above load after 327 hours' application.

Time to recover.	Set.	Time to recover.	Set.	Time to recover.	Set.
hours.	mm.	hours.	mm.	hours.	mm.
0	2·41	8	1·73	48	1·32
2	1.94	24	1·46	74	1·30*
4	1·74	32	1·38	....	....

*At least ·5 mm. of this set was due to the indentation of the beam at the points of support.

The next piece of the series, No. 7, was subjected to a load of two-

After 21 days' rest, the beam was again put in the machine, and the same load of 374 lbs. was alternately applied, and taken off with the following results:

Weight.	Deflection on application of load.	Time applied.	Deflection.	Set.	Time to recover.	Set.
lbs.	mm.	hours.	mm.	mm.	hours.	mm.
374	16·62	26	18·22	1·45	16	·53
"	17·34	8	18·54	1·60	15	·66
"	17·52	4½	18·49	1·70	15½	·67
"	17·75	9½	18·83	1·90	14½	·97
"	17·95	9½	19.00	1·97	14½	1·08
"	18·10	48	19·56	2·68	24	1·48
"	18·38	9½	19·52	2·50	14½	1·47
"	18·38	9½	19·48	2·40	14½	1·53
"	18·58	9	19·73	2·60	15	1·54
"	18·70	48	20·35	3·15	9	1·67
"	19·15	24	20·86	3:40	15	1·75
"	19·55	24	22·02	4·30	24	2·26
"	20·12	24	21·86	4·20	9	3·97
"	21·85	756	26·80	7·70	24	5·61
"	24·90	105	27·16	7·40	24	5·70

NOTE.—The numbers in column 5 show the set of the beam immediately after the removal of the load, which was suspended from the beam the number of hours given in column 3.

thirds of its breaking weight, which it carried 24½ days, and then gave way as the others had done.

The increase in the deflection of this beam was quite regular, as is shown by the diagram on Plate 4. The deflections are given in Table IX.

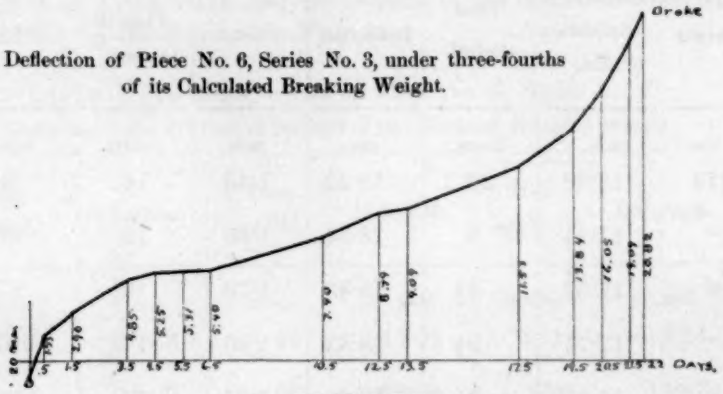


PLATE III.

Having proved that two-thirds of the so-called breaking weight of a beam is more than it will carry permanently, the next beam was subjected to only one-half of its calculated breaking weight.

This load was kept on the beam 49 days, during which time the

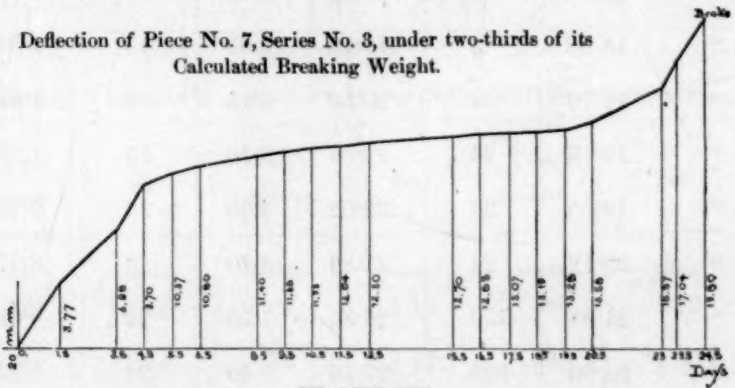


PLATE IV.

deflection increased from 13·4 mm. (0·527 in.) to 18·55 mm. (0·73 in.)

It was then necessary to remove the beam from the machine that

TABLE VIII.—*Deflection of Piece No. 6, Series No. 3, under a load of 399 lbs., or three-fourths of its Calculated Breaking Weight.*

Time applied.	Deflection.	Time applied.	Deflection.	Time applied.	Deflection.
days.	mm.	days.	mm.	days.	mm.
0	19·12	5·5	25·31	17·5	31·53
0·5	21·53	6·5	25·40	19·5	33·84
1·5	22·90	10·5	27·40	20·5	36·05
3·5	24·85	12·5	28·79	21·5	39·09
4·5	25·25	13·5	29·09	22	*40·82

* Broke within 12 hours.

TABLE IX.—*Deflection of Piece No. 7, Series No. 3, under a load of 401 lbs., or two-thirds of its Calculated Breaking Weight.*

Time applied.	Deflection.	Time applied.	Deflection.	Time applied.	Deflection.
days.	mm.	days.	mm.	days.	mm.
0	20·07	9·5	31·68	18·5	33·19
1·5	23·77	10·5	31·93	19·5	35·28
3·5	26·98	11·5	32·04	20·5	33·58
4·5	29·70	12·5	32·30	23	35·57
5·5	30·37	12·5	32·70	23·5	37·04
6·5	30·80	15·5	32·85	24·5	*39·80
7·5	31·40	16·5	33·07		

* Broke within 12 hours.

the latter might be used for other tests. The "set" of the beam on the removal of the load was 4·35 mm. (0·171 in.)

Seven days after the load was removed it was again put on the beam and allowed to remain 77 days, when it was again removed that the beam might be put on a temporary frame and kept there, with the same load suspended from it, until it broke.

The "set" of the beam on the second removal was only 3·76 mm. (0·148 in.), being less than what it was after the first removal.

The deflections of the beam are given in Table X, and the diagram on Plate No. 5 shows the increase in the deflection for both applications of the load. The upper line denotes the deflections under the second application of the load.

TABLE X.—*Deflection of Piece No. 8, Series No. 3, under a load of 301 lbs., or one-half of its Calculated Breaking Weight.*

Time applied.	Deflection.	Time applied.	Deflection.	Time applied.	Deflection.
days.	mm.	days.	mm.	days.	mm.
0	13·40	14	16·77	25	17·14
1	14·03	15	16·93	26	17·17
3	15·51	17	16·89	27	17·41
4	15·58	18	16·89	29	17·51
6	16·34	19	16·97	31	17·59
8	16·52	20	17·07	33	17·76
10	16·53	21	17·14	38	17·97
11	16·66	22	17·14	45	18.45
12	16·83	24	17·10	49*	18·55
13	16·79				

* After taking the last deflection the load was removed from the beam, when the centre of the beam returned to within 4·35 mm. of its original position.

After seven days, the load of 301 lbs. was again put on the beam and allowed to remain, causing the following deflections:

TABLE X.—(*Continued.*)

Time applied.	Deflection.	Time applied.	Deflection.	Time applied.	Deflection.
days.	mm.	days.	mm.	days.	mm.
0	13·20	23	15·70	59	16·84
1	14·25	38	16·18	63	16·95
3	14·61	43	16·43	66	17·05
5	14·90	47	16·50	68	17·11
10	15·25	48	16·52	71	17·15
13	15·37	53	16·64	77	17·32
18	15·73	54	16·70	load removed, set 3·76 mm.	

As this beam continued constantly to deflect, and as this increase in deflection is still going on, it seems to the writer that it must ultimately break under this load, for when the deflection reaches a certain

Deflection of Piece No. 8, Series No. 3, under a load of 301 lbs., or one-half of its Calculated Breaking Weight.

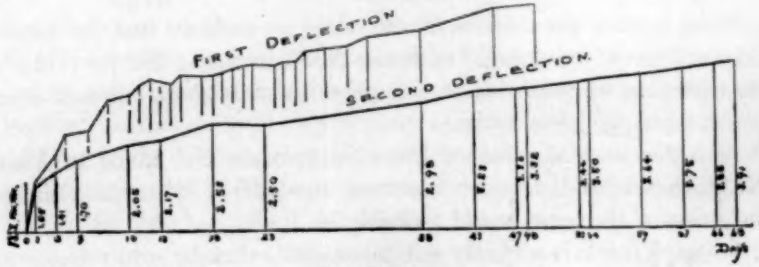


PLATE V.

limit it will, as is shown by the other pieces, rapidly increase until it breaks.

Observations on Tables I, II, and III.

Comparing Tables II and III we find a great difference in the values of the modulii of rupture for the two sets of experiments, although the planks from which the pieces were cut were selected from the same lot of lumber and dried the same length of time. The only reason which the writer can give for the low value of R in the 3d series is that the plank was sawn from the outside of the tree. It will be noticed that the values of R ran very high for the pieces in Series No 2, also that the average value of R for Series No. 1 is only about 8 per cent. less than that for Series No. 2, while it is about 23 per cent. greater than the average for Series No. 3. This would lead one to infer that ordinarily dry lumber does not have its strength materially increased by being kiln-dried.

Comparing Tables I and II we see that the average value of the modulus of elasticity for the beams of unseasoned spruce is fully as large as that for the kiln-dried spruce. The beams in Table I, though denoted as unseasoned, were fully as dry as timber which has been in an ordinary building three months, but it was not artificially dried.

If we compare the ultimate deflections of all the pieces with their modulus of rupture we shall find as a rule that those beams which were the strongest bent the most before breaking.

[The values of E in the Tables I, II and III were computed from the expression $E = \frac{Wl_3}{4\Delta BD_3}$, Δ denoting the deflection in inches. The values of R were computed from the formula $R = \frac{3}{8}\frac{Wl}{BD_2}$]

From further observations of the tables we shall see that the deflections of Pieces Nos. 6 and 7 of Series No. 3 increased 100 per cent., or the deflection when the load was applied was only about one-half what it was when the beam broke.

Also that the deflection of Piece No. 9, Series No. 2, and of Piece No. 8, Series No. 3, is much less than one-half of what the ultimate deflection of the beam would probably be.

Hence I think it perfectly safe to conclude that for spruce beams of small sections a load which will produce a deflection of one-half of the maximum deflection of the beam before breaking will ultimately break the beam.

From a study of Tables VII and X it would appear that a load of one-half the so-called breaking load of a beam does not injure the beam when applied only for a short time; for it will be noticed that for both, Piece No. 9, Series No. 2, and Piece No. 8, Series No. 3, the deflection of the beam upon the second application of the load was almost the same as upon the first application, the difference being slight indeed.

Furthermore, it will be seen from the diagram on Plate No. 5 that the deflections of Piece No. 8 were greater on the first application than on the second, although the increase in deflection was in about the same proportion.

From an examination of the diagrams it will be seen that for the

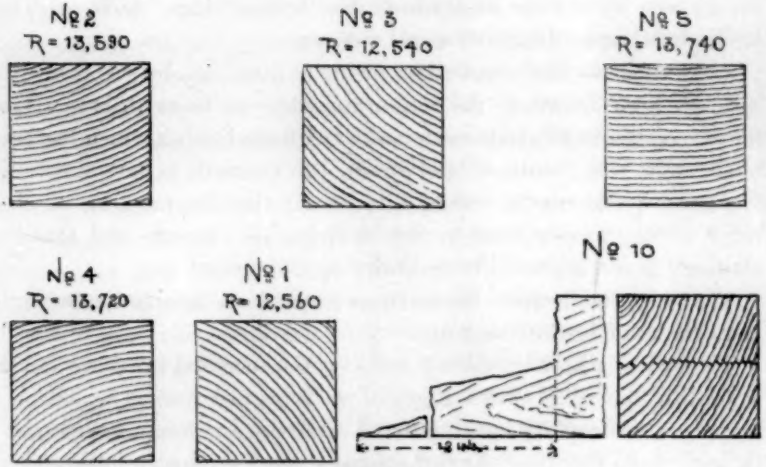


PLATE VI.

first twelve or twenty-four hours after the load is applied the deflection rapidly increases, and that from that time until about two or three days before the breaking the increase in the deflection is generally very regular, increasing again very rapidly as it nears the breaking point.

Effect of the "annual rings" on the strength of a beam.—After computing the modulii of rupture for the first five pieces of Series No. 2 the writer was surprised to see that three pieces had nearly the same modulus, and that the remaining two pieces also agreed almost exactly, but that there was a great difference between the modulii of the three and of the two pieces.

The writer could think of no reason for this phenomenon until

examining the fractured section of the beams, when it was discovered that in the three beams which had the high modulii the "annual rings" were parallel or nearly so with the top and bottom surfaces of the beam, while in the other two the "annual rings" made an angle of about 45° with these surfaces.

The figures on Plate 6 show the angle which the "rings" made with the top and bottom surfaces, and also the value of the modulus of each piece. Piece No. 10 was cross-grained, and as it broke under a very light load and by "slivering," it was thrown out from the series and is not given in the tables. The row of short lines across the centre of the section of this beem shows the manner in which the rings were broken—at right angles to their surface. We think that this plate shows very plainly the effect which the "annual rings" have upon the strength of spruce beams of small sections.

Conclusions.—The conclusions which may be drawn from the research here described the writer considers to be as follows: That for spruce beams of small section selected from lumber which has been moderately well seasoned and dried, the strength is not materially increased by the timber being kiln dried; that the modulus of elasticity is not proportional to the modulus of rupture and that the elasticity is not increased by kiln-drying the timber.

That with small spruce beams those which have the greatest strength bend the most before breaking.

That when a load between $\frac{1}{2}$ and $\frac{7}{8}$ of the so-called breaking weight is applied to a small spruce beam it produces a deflection which for a few few hours rapidly increases until the beam has fairly settled under its load; from this time the deflection increases gradually until a short time before breaking, when it increases more and more rapidly.

That a load of one-half of the so-called breaking weight if applied but for a few days does not injure such beams.

That a load which will cause such a beam to deflect one-half of its maximum deflection before breaking will ultimately break the beam.

That under the most perfect conditions small spruce beams will not permanently support a load of one-half their so-called breaking weight.

That the position of the annular rings in spruce beams of small section materially affects the strength of the beams, their strength being the least when the rings make an angle of 45° with the top and bottom surfaces of the beam.

The writer agrees with Prof. R. H. Thurston in considerlng 5 as

the least factor of safety which should be used for wooden beams under an absolutely static load.

In conducting this investigation the writer has received much assistance and encouragement from Mr. Silas W. Holman, of the Institute of Technology.

Boston, Mass., April 9, 1882.

THEORY OF THE STEREOSCOPE.*

By W. Le Conte Stevens.

Sun-painting and sun-sculpture are names that have been applied to the products of two sciences which have grown up together during the latter half of the present century. The chemistry of light has given us the art of photography; the study of twin photographs has enlarged our knowledge of the physiology of vision; chemical optics and physiological optics have thus been developed together. A single photograph, viewed with a single eye, may present the perspective illusion of the painter's art; a pair of photographs, properly taken, and properly viewed with a pair of eyes, presents an illusion that the painter may seek but the sculptor only can fully attain.

The camera and the stereoscope are no longer novelties; but the theory of the latter instrument, advanced by the physicist who invented the form most generally in use, and currently taught since his time, cannot be accepted to-day. The writer is aware that, in consenting to present a *résumé* of some recent investigations on this subject, he may be giving to the readers of this journal what some of them have already seen expanded by him elsewhere; if so, no claim can be made to a renewal of their attention.

Before criticising any theory currently taught, it may be well to state it clearly. It has long been known that the judgment of locality is more accurate when two eyes are used than in monocular vision. Kepler† in 1604 stated that the distance between the two eyes is a base-line which we employ in estimating the distance of a point by a species of visual triangulation. After the invention of the stereoscope by Wheatstone in 1838, Kepler's principle was applied to the deter-

* The following summary of the author's investigations was prepared for the Journal by special request.—W. H. W.

† Paralipomena, pp. 62–66, 1604.

mination of the apparent position of the object viewed, rays from the twin pictures being reflected into the observer's eyes, as if coming from a single object in front. The refracting stereoscope, devised by Brewster in 1849, shortly before improvements in photography made it easy to multiply stereographs at will, soon became popular; and the theory of visual triangulation at once found its way into our text-books in physics, where it may still be seen. The diagram generally employed is that of Fig. 1, or its equivalent. The construction of the stereograph being explained, it becomes obvious that the distance between corresponding background points on the twin pictures must exceed that for the foreground. Let aa' be the foreground interval, bb' that for the background; the lenticular prisms being interposed between the stereograph and the eyes, R and L. Then by refraction a and a' appear combined at A, b and b' at B. The two visual lines form with the interocular base line, RL, an isosceles optic triangle,

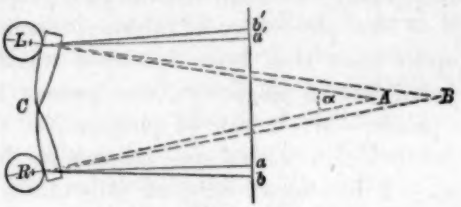


Fig. 1.

whose angle at the vertex, a, can be measured. Let i = base line RL; then for the distance, D, of the vertex, A, from either eye, we have, $D = \frac{1}{2}\, i$. cosec. $\frac{1}{2}\, a$.

From this equation it is obvious that if such a relation can exist between the stereograph, the lenticular prisms, and the eyes of the the observer, as to make the visual lines parallel or divergent in order to retain single vision, the formula brings a result that is physically impossible. If its generality be thus disproved, it becomes interesting to inquire whether it is really applicable when the optic angle, a, is positive, and if not, whether there is any basis for such a theory of stereoscopic perspective as has been current for forty years.*

Most persons find it not easy to direct the eyes in a manner different from that which the ordinary necessities of vision have made habitual. The power to do so can be acquired by the exercise of a little perse-

* Wheatstone, Physiology of Vision, Phil. Trans., part ii, 1838. Brewster, The Stereoscope, pp. 50–100, 1856. Ruete, Das Stereoscop, p. 46, 1860.

verence, but to obviate the necessity of this, refracting glasses in the stereoscope are commonly employed. If without these a screen be used to hide each picture of the stereograph from the eye on the side opposite, and thus remove the temptation to converge the visual lines to the same external point, each eye looks at the picture immediately in front, and it is easy thus to secure single binocular vision. If the interval between corresponding points on the stereograph equal or exceed that between the observer's optic centres, there can be no meeting of visual lines in front. The writer has often thus secured stereoscopic effects without using the stereoscope, and without employing any screen, when conditions were such as to necessitate 4° or 5° of optic divergence. Indeed this relation between the visual lines is by no means uncommon in using the stereoscope. It implies uncomfortable strain upon the external rectus muscles by which the eyeballs are rotated outward. Probably few persons have ever used this instrument without experiencing discomfort at times.

In 1861 a German physiologist, Burckhardt,* called attention to the fact that similar pictures could be binocularly combined with slight optic divergence. The same observation was independently made during the following year by Professor C. F. Himes,† now of Carlisle, Pa., who published a paper on the subject in the *American Journal of Photography*, and subsequently contributed a series of papers on binocular vision to the JOURNAL OF THE FRANKLIN INSTITUTE. Helmholtz also refers to stereoscopy by the same method, but makes no provision for it in his mathematical discussion of the stereoscope. De-pite these publications, the theory of visual triangulation is still generally reproduced in our text-books.‡ So far as the writer is aware, no analysis of vision by optic divergence has been made until recently, although its possibility has long been known.

If mathematics be applied to the theory of the stereoscope it must be restricted to the preparation of the stereograph, in which account must be taken of all the laws of mathematical perspective. So far as we can explain the illusion produced in binocularly regarding the

* Helmholtz, Optique Physiologique, p. 827, 1867.

† *American Journal of Photography*, vol. v, p. 114, Sept. 1, 1862. JOURNAL OF THE FRANKLIN INSTITUTE, 1872.

‡ Jackson's Optics, p. 121, 1867. Helmholtz, Optique Physiologique, p. 812, 1867. Ganot's Physics, p. 486, 1872. Deschanel's Natural Philosophy, p. 950, 1875. This list of citations could be much extended.

stereograph, explanations must be based on what we know of the physiology of sensation; and the external intersection of visual lines may be completely thrown out of consideration. The interpretation which we put upon our sensations depends upon individual experience. In ordinary vision, with both eyes directed upon a given object, a pair of slightly dissimilar retinal pictures are produced, and the result is an unconscious judgment, instantly reached, in regard to its size, form and distance. At the same moment there is a particular degree of contraction in the rectus muscles controlling the eyeballs, and the ciliary muscles encircling the crystalline lenses. The muscular sense contributes along with the retinal sense towards the determination of the judgment. If there be any disturbance in the co-ordination of sensations that are usually associated, the judgment is vitiated and often more or less physical pain is felt as an accompaniment. Assuming that conditions are such as to produce the least possible disturbance, all we can affirm, in reference to the judgment of locality and form put upon the stereoscopic image, is that experience has taught us to interpret retinal sensations that are slightly different in the two eyes, as the signs of an external object possessing three dimensions in space, when the images are made upon parts of the concave retinal surfaces which bear to each other the mathematical relations imposed by the presence of such an object in normal binocular vision. The locality is additionally judged by taking into consideration, consciously or unconsciously, all the peculiarities of each image, and at the same time the muscular sensations which experience has taught us to associate with retinal sensation. If we discard the latter consideration, it should make no difference whether the visual lines are convergent, parallel or divergent, provided there be no change in the mutual relations between the two retinal images.

Supposing binocular vision to be perfectly normal, we may consider the centre of the yellow spot on each retina as a zero-point from which retinal latitude and longitude are measured; and the position of each point of a retinal image corresponding to a given external object may thus be theoretically fixed. It is at once obvious that a point nearer or farther than that upon which attention is directed must be imaged in the two eyes upon retinal points that have not the same longitude. Experience has caused us to associate external singleness with perfect correspondence in position of the two retinal images; and on this has been based the unproved theory that each rod or cone beneath one

retina is in nervous connection with a particular mate in the other eye, thus making single binocular vision a product of anatomical structure. The difference in longitude between the retinal points on which the same external point is imaged may be called the retinal displacement. Theoretically, there should be double vision whenever the slightest retinal displacement exists. Practically, when this displacement is considerable, double images can be perceived; but thus far no minimum limit has been definitely assigned at which we can be sure that the perception of duplication begins. No mathematical interpretation can be put upon such a theory, whether we regard the correspondence as the product of experience or of anatomical structure. The eye is far from being a perfect optical instrument, and focalization is hence never exact. Each sensitive point impressed becomes at once the centre of an area of disturbance, and hence a pair of slightly dissimilar retinal images may apparently coalesce without the perception of duplication in any part. The resultant perception is attended with an enhanced recognition of three dimensions in space, but no fully satisfactory answer has yet been given to the question, how it is that we determine by the nature of the combined retinal image whether imperfect coalescence is due in any given case to the distance of the object being greater or being less than that of the point to which the visual lines are directed.

Assuming that the retinal displacement is great enough to cause apparent duplication of points in the background of a stereoscope picture when the foreground is regarded, and *vice versa*, it is easy to understand how the muscular sense may conduce toward the perception of depth in space. If the eyes be made to follow an object that is brought near and then moved off, as the optic angle increases with the approach of the object, the internal rectus muscles become more strongly contracted. With its recession they become relaxed, and the external rectus muscles become contracted. An association between the muscular sensation and the external reality that ordinarily gives rise to it is soon established. If by any means abnormal vision can be induced, the suggestions due to muscular sensation are still the same in kind. Thus, in Fig. 1, if the attention be transferred from the conjugate points a and a', to b and b', the external rectus muscles must be contracted, and this at once suggests the idea of greater remoteness for the new points regarded. Such increase of contraction would still be

necessitated even if the visual lines, R a and L a', had been parallel, or slightly divergent, instead of convergent.

Again, if an object be held a few inches in front of the face, in addition to the contraction of the internal rectus muscles to secure proper direction of the visual lines, we have the ciliary muscles strongly contracted to secure distinct focalization; and the unconscious recognition of proportionality between these associated contractions becomes habitual. If the momentary necessities of distinct vision be such as to disturb this association, the result is either confusion or error in interpreting the sensation. In Fig. 1 the convergence of visual lines, when a and a' are regarded, is adapted to an object whose position is A, while for each eye the ciliary accommodation is for the smaller distance R a or L a'. The result is slight discomfort and uncertainty in the judgment of distance. The ciliary muscles are too much contracted

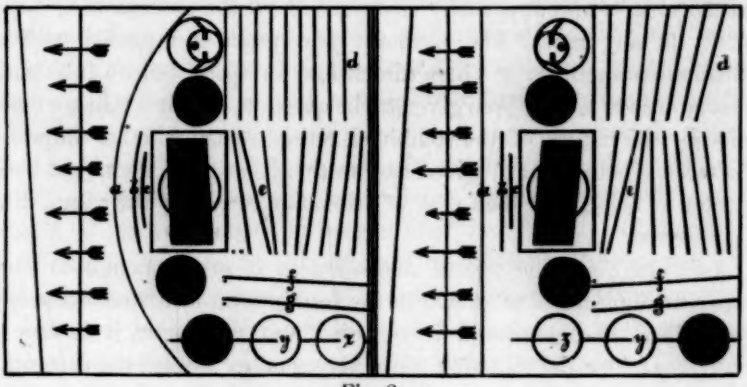


Fig. 2.

for natural association with the condition of the rectus muscles. This disassociation obviously becomes more painful if the distance $a\ a'$ is increased so as to necessitate optic divergence. But in no case can perfect accordance between the adjustments of the ciliary and rectus muscles be secured under the conditions imposed in ordinary stereoscopic vision.

The duplication of images for background points when the foreground is seen single, and *vice versa*, is shown in the accompanying stereograph, Fig. 2, which has been made with a variety of stereoscopic displacements in different parts. The binocular combination can be easily effected, either with the aid of a stereoscope or by use of a screen of card-board, rested with one end against the triple line and the

other against the forehead of the observer. The lines marked *a* will be perfectly combined into a single curve at the middle, but duplicated above and below, the point where theduplication begins being indeterminate. No duplication of the lines *c* is perceptible. There are many other peculiarities which the reader will discover by continuing the examination, scanning separately each part in succession. The truncated cone, the oblique parallelogram, the warped surface, and the wind-vanes will repay close attention. The stereograph is so constructed as to exclude entirely the ordinary elements of mathematical perspective; hence any perception of depth in space is the product of binocular vision alone.

Even with such a stereograph as this the interpretation unconsciously put upon the binocular image may be much modified by varying the muscular conditions under which the perception is attained. In studying these effects, for which the term physiological perspective is con-

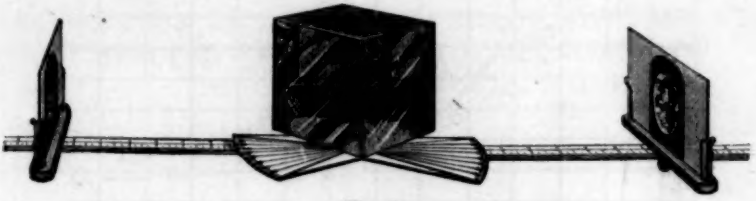


Fig. 3.

venient, the writer devised a graduated reflecting stereoscope, shown in Fig. 3. It is simply an improvement upon Wheatstone's stereoscope, which never came into popular use. A pair of conjugate pictures are placed on the arms, each at a measured distance, such as 50 cm., from the pivot on which these move, while the eyes are as near as possible, one in front of each oblique mirror. If the arms are pulled forward, optic convergence becomes necessary to receive the reflected rays and retain single vision. This involves increased contraction of the internal rectus muscles and associated contraction of the ciliary muscles. Since the real distance of the pictures remains unchanged the ciliary muscles should not change their condition if distinct focalization is retained. The contraction of the internal rectus muscles produces the illusive judgment of nearness; and since the visual angle subtended by the diameter of the picture remains constant, its estimated size diminishes with the estimated distance. The value of the optic angle enclosed by the visual lines is obtained from the divided circle, and the distance of the

optic vertex is easily calculable by the formula already deduced. By pushing the arms slightly back, as represented in the figure, to retain single vision, the excess of contraction must be in the external rectus muscles. As the visual lines are now divergent, the optic angle is negative; the illusive effect is recession of the binocular image, while the distance of the object, and hence the visual angle subtended by it, remains constant.

The mean result of a large number of experiments is shown in the curve, Fig. 4, where successive values of the optic angle are taken as abscissas and estimated distances of the externally projected binocular image as ordinates. The stereoscope was manipulated by an assistant, who

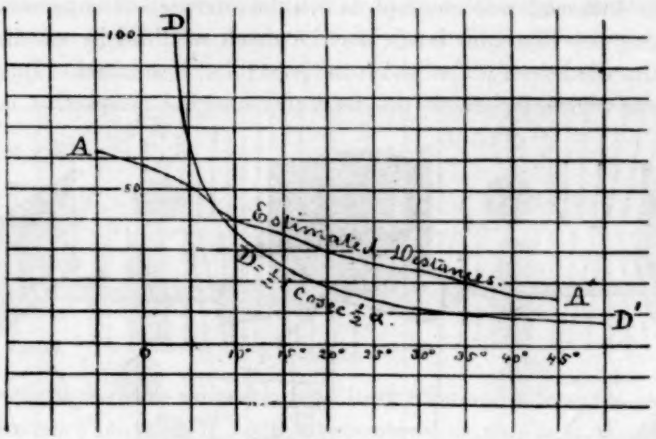


Fig. 4.

also kept the records, of which the writer remained ignorant until after the series of experiments was completed. To prevent too great fatigue these were made at different times in groups. The curve DD′ is calculated from the formula, and gives the successive theoretic positions of the image if the theory of visual triangulation be true. To this curve the axis of ordinates is an asymptote. The curve AA' gives the successive positions as observed under the abnormal muscular conditions imposed, the optic angle being varied from —5° (divergence) to +45° (convergence). The two curves intersect quite near to the point whose ordinate is D = 50 cm., corresponding to $\alpha = +7° 20'$; showing that the formula roughly expresses the truth for perfectly normal vision. But on each side of this point the difference between theory and observation becomes striking, the estimated distance and

size of the image being greater or less than that of theory, according as the optic angle is greater or less than that of normal vision. The visual angle remains constant while the optic angle varies, and suggestions due to the condition of the ciliary muscles are antagonistic to those due to the condition of the rectus muscles. As might be expected, the probable error of the whole series is large, being ± 8 mm., and the curve AA' is not regular, but its general import is unmistakable. The localization of the external image is in no way dependent upon intersection of visual lines, but largely affected by the temporary condition of the muscles of the eyes. The curve AA' represents the result of experiments upon the writer alone; but similar results have been obtained from the examination of several other persons, slight variations being such as might be expected from difference in personal organization.

REPORT ON EUROPEAN SEWERAGE SYSTEMS, WITH SPECIAL REFERENCE TO THE NEEDS OF THE CITY OF PHILADELPHIA.

By Rudolph Hering, C.E.

(Continued from page 201.)

III. Street Inlets or Gullies.

After having briefly treated of that part of the system which collects and conveys the house sewage to the sewers, which is to a certain extent in private hands, I will now examine into the design and construction of the appliances for collecting and conveying the street-wash to the sewers.

In Philadelphia these appliances are called simply inlets, in other cities, catch-basins and in Europe, gullies. A great number of designs are in use.*

Inlets in our city are usually placed at the corners of street intersections. The usual size No. 1 has an opening of 4 feet 6 inches × 10 inches, a basin for catching silt 2 feet below the outlet, 4 inches 6 feet long and 1 foot 4 inches wide, with a water-trap 4 inches deep. They are built of brick, with flagstones for the back and the trap, and have

*See Appendix No. 4.

a cast iron cover. A so-called "neck" or branch of brick, 2 feet in diameter connects them with the sewer. A common trouble experienced is a failure of the trap and the escape of sewer air.

It is not an uncommon case, as already mentioned, that the intersection of several streets forms a depression, and this causes the inlets to become more easily and rapidly silted up and in consequence thereof, sometimes, the territory to be flooded. In Europe these objections are not experienced, or only in a slight degree. There the gullies are less expensive and less unsightly. The location is rarely at the immediate corner of the intersection, mostly a short distance above it. Depressions, such as we have, are consistently avoided. The inlets are smaller, are placed closer together, and the attention given to their cleaning is much greater in all of the larger cities than here.

In examining the designs we find some that have silt-basins to catch the sand and heavy or bulky matter, washed into them from the streets, and some that discharge directly into the sewer. The latter I noticed only in Paris and Hamburg. In both of these cities circumstances justify the absence of silt-basins. The great attention given to street cleaning in Paris, as well as the facilities for cleaning the sewers, has made it seem expedient to wash much of the road detritus off the surface into them and then to artificially remove it through them to an outfall. In Hamburg the silt is not objectionable in the sewers because it can be readily removed at any time, by natural flushing. The Alster lakes, situated almost within the city, are used for this purpose and from them a large quantity of water can be sent through the greater number of sewers at a velocity sufficient to wash the silt into the river.

In all other cities, catch-basins were preferred even where the streets are well cleaned. The designs differ in different places. The size is principally regulated by the character of the pavement and by the degree of care which can be given to the cleaning of the streets and sewers.

In Frankfort, a bucket perforated near the top, is placed in the basin to catch the silt, and when filled, can be readily lifted out, emptied and returned. In other cities the silt is removed by scoops.

When sewers are properly built, ventilated and maintained, traps are almost or quite needless; the air in the sewer does not become so foul as to be objectionable when it arises from the inlets. In Paris and Hamburg they were left out at the beginning, and their absence

has never caused the slightest nuisance. Several cities have had the traps removed, prominently among which is Leeds, and it was found that where the sewers were well cleaned and the inlets were not too near the windows, the odor, if there was any, escaping from them, was unnoticed. The additional aid thus given to ventilation, even further reduced the development of noxious gases.

To determine the design of an inlet which is best suited to our circumstances, I shall examine into each one of its features separately.

Until the streets are cleaned in a manner and to a degree which is even rare in Europe, the silt-basins can evidently not be omitted, especially as we have no natural means of flushing our sewers with large quantities of water.

If we cannot do without the basin, the question will then be, of what size to make it? Here again the usual condition of our streets will not permit as small a size as is common in Europe. The comparatively great amount of dirt and silt left on our streets would quickly fill them up during a sudden storm, or, if kept sufficiently stirred up by a heavy shower it would be washed into the sewers and thus defeat the object of the basin. In the sewers the silt acts as a retarding element to the flow of sewage by making a flatter channel, which causes further deposits and also a mingling of the silt with the decomposing filth. As insufficient care in the cleaning of streets, compared with European cities, is a given fact for us, it is necessary to guard against the ill effects upon the sewers as much as possible. The basins, therefore, should be large and deep enough to retain a reasonable amount of silt, varying with the character and width of the road, which a careful examination may determine. Yet this amount need not be greater than what accumulates from one storm, as it should be removed early, before decomposition can make its retention objectionable. For the paved sections of our city I think a basin holding from 6 to 12 cubic feet of silt, according to the size and grade of the surface drained, is of ample capacity. For macadamized streets and rural sections a greater size is necessary.

The next feature of the inlet to be examined is the trap. Unless our sewers were built and maintained as well as those in European cities, where inlets have no traps, it would not be advisable for us to omit them. Of all traps the water-seal is for this purpose the best, simplest and most economical. During a long drought it may, how-

ever, be necessary to run water into them to guard against unsealing by evaporation.

Another part of the inlet is the "neck," or connecting branch with the sewer. As its service is to lead away the water entering the inlet, its size is thereby determined. A diameter from 6 inches to 12 inches is in all cases sufficient. I have nowhere, except in Paris and Vienna seen greater ones, even under essentially the same conditions as in Philadelphia. The great disatvantages resulting from the custom of building necks of 2 feet in diameter are the same as those which I shall mention later, when speaking of the sewers themselves. It will suffice now to state that terra-cotta pipes, of diameters only sufficient to discharge the maximum quantity of water, will give much less chance for deposit, and for that reason should be preferred. They can be inspected and cleaned as well, if they are laid in straight lines; they are as durable and not more expensive.

In Paris the necks (*branchements de bouche*) are large enough, like all sewers, to be walked through, but they are frequently cleaned. Notwithstanding this, they are the least efficient part of the system, and the odor arising from the street-inlets has been traced mainly to the decomposing matter lodging in them, than to the air from the sewers. In Vienna, the necks, also large enough to be entered, are but little better than our own, although they are frequently and regularly cleaned. On the other hand no complaint has arisen in any city, as far as I could ascertain, from the use of terra-cotta pipes. Little doubt, therefore, remains in my mind that much of the odor escaping from our inlets is due, as in Paris, to the decomposition of matter in the necks. And this seems to be confirmed by the fact that when broken into they present as foul a condition as the average branch sewer.

I will now consider the proper location for the inlet. Our custom is to place them directly at the intersection of the curblines of two streets. I found this rarely done in Europe, not only because it is unsightly, but because it makes a deep gutter for pedestrians to step over and into which the wheels of vehicles are apt to slip in turning the corner, which strains or even breaks them. Still another reason is that the position across a corner is not the best one to receive the water as it is obliged to turn a considerable angle, from 45 degrees to 135 degrees, before it drops into the basin, which impedes its velocity, and

therefore, needs a larger inlet than if it is situated, as in Europe, on the line of the curb in the block.

When the grade of the gutter continues around a corner, the best location for the inlet is at a point about 8 or 10 feet above the side-walk crossing, which entirely abolishes the gutter at the corner. When the grade of the gutter is lowest at the intersection, then it may be a question to consider in such case whether it is best to put one large inlet at the corner or two smaller ones, each about 20 feet from it. In frequented and principal streets, the latter is always preferred in Europe. In small streets, or in the suburbs, the corner inlet would not be so objectionable. There is no reason why the same plan should not be as advantageous in our own city.

Inlets, when they have catch-basins attached, are, at best, more or less objectionable, unless they are cleaned frequently and carefully. They should, therefore, be avoided, whenever possible, unless they can relieve a greater nuisance. There is no objection to rain-water running in and over the streets in moderate quantities during a storm. If inlets, therefore, are used only for the purpose of receiving rain-water, which is the case when a sewer has been built in a street and the houses have been connected, then they can be left out, both for a short distance from the river and from the water-shed line of the drainage area. This distance is governed by the topography and can easily be as much as several blocks. For instance, all the water falling east of Front, or even Second street, between Fairmount and Washington avenues, might readily run off on the surface into the Delaware River. At the highest parts of many of our areas the storm-water could also rnn over the surface for two or three blocks, before it would accumulate so as to become troublesome and require an inlet. These points are generally considered in Europe, and a reduction of the number of inlets is effected. In fact, it has been proposed* to keep the rain-water entirely on the streets by leading it away in covered gutters, but this I am confident is impracticable, at least in our city.

To have the inlets a short distance above the corner and to let rain-water run over an intersection of streets requires an adjustment of the grade of the pavement, which must briefly be noticed. In the first

*Col. G. E. Waring, Jr. Sanitary Condition of New York. *Scribner's Monthly*, June, 1881.

case, it can be raised to about three or four inches below the side-walk, giving an easy step and avoiding a gutter-crossing. In the other case, the gradients and crown of the intersection would require to be such that water can run across readily. Modern pavements will generally allow this condition. The Belgian, asphalt and wood pavements require but a slight chamber, and with them this saving in the number of inlets, often made use of in Europe, could also be effected here.

Regarding the construction of inlets, I must state, that our practice is inferior to that which I have noticed elsewhere. When a silt-basin is necessary, it must be water-tight, but especially so when the water is to form a trap against the exit of sewer-air. The use of flagstones to face the walls is not likely to make as water-tight a basin as a well cemented wall of brick work alone, or as one made of iron or concrete, the materials commonly used in Europe. Nor is the absence of an inspection, while they are being built, likely to decrease this trouble. From the designs I have collected it will not be difficult to adapt one or the other to our conditions as mentioned, which would be much more suitable than our present one.

The cost of inlets, such as would be proper will not be greater than the cost of the present ones, provided the quality of material and workmanship is the same. And a saving may even be effected by a judicious distribution, especially in connection with the paving of the streets, near the highest and lowest parts of the drainage areas, as indicated.

Finally, whether the inlets discharge water into the sewers of a combined system or into separate rain-water channels, it does not alter the above-mentioned points governing their design, except that it may be expedient and advisable in the latter case to omit the trap and thereby to obtain better ventilation.

IV. Sewers.

I have now examined those parts of the system by which the sewage is collected and brought into the sewers. It will next be in order to inquire into the features of the sewers themselves.

(*a*) Shape.—All sewers in Philadelphia are, as a rule, built of circular shape, from the largest to the smallest, except where sufficient height is not obtainable, when sections with flat inverts of varying forms are used. That these shapes are essentially faulty, and undoubtedly a most prominent cause of the present objectionable con-

dition of the sewers I shall endeavor to show by a theoretical consideration confirmed by the long practical experience had elsewhere.

The best shape of a channel in which flowing water is to receive the least possible resistance to its flow is the semi-circle. As the sanitary requirements of a system demand in the first place a quick and complete removal of the sewage, every element of design and construction which favors this should therefore be considered.

A sewer for the combined system is to answer two objects, the conveyance of a continual stream of sewage and of the periodical stream of storm-water, which is many times greater in quantity. It would, therefore, strictly be necessary to give each of the two streams a semi-circular section. This is impossible in the same channel, and only an approach to it can be had at best. If a semi-circular section is given to the sewage, the storm-water must have a different one, and *vice versa*.

To decide which of the two cases is to be preferred, it must be considered; that the sewage is a continuous stream, whereas rain-water enters periodically; that, further, sewage is a heterogeneous mas consisting of floating and suspended glutinous particles which readily adhere to the frictional surface, while rain-water is free from such matter and comparatively clean; and, finally, that the sewage, from its decomposing nature, should be conveyed as swiftly as possible through the sewers, while with rain-water this requirement is not so needful.

From all of these essential points it will be seen that the semi-circular section should be given to the sewage in preference to the storm-water, because its flow is continuous and its mass heterogeneous, carrying glutinous and adhering matter subject to rapid decomposition. If the usual flow is carried in a channel of this shape the storm-water must be conveyed in some other. The combination gives the common egg-shape. That this shape, which *theoretically* is shown to be superior to the circle, is also *practically* the best, has been shown by a long experience in Europe. Not one of the large cities with any pretence of a sewerage system has retained the circular section for large sewers, carrying both rain-water and sewage. All have long ago adopted the egg-shape, and not a single objection is made to it, whereas the circular form has a very serious one.

The relatively small amount of sewage is necessarily spread out to a shallow segmental section. This decreases not only the mean velocity,

but particularly the velocity along the margin, and, therefore, causes the suspended particles to deposit. For this reason we usually see in a circular sewer a stream of sewage meandering along the bottom in irregular lines, building up a small bank of filth on each side, whereas, by a properly designed egg-shaped section this is exceedingly rare, if ever, observed.

The proper shape of a "combined" sewer must then be determined as follows: The radius of the invert, which is to carry the sewage, should be nearly the same as for a semi-circular channel, just large enough to be filled by the ordinary flow of sewage. The other dimensions are governed by the quantity of rain-water to be provided for, and by the laws of stability. An egg-hape which is thus obtained is the only rational one for the combined system. Some sewers, however, require a different treatment. An intercepter, which is designed only for the conveyance of sewage, and, therefore, a more uniform flow, should according to what has been said, have a circular section, and in Europe all such sewers have this form or a near approach to it. Again, a sewer which is so small that it can be built of vitrified pipes is also given a circular section with advantage, for not only their smoothness prevents much adhesion along the sides, but also the greater facility for obtaining a true circular form for every single pipe, therefore, avoiding a series of projections which are exceedingly detrimental to the flow of sewage, makes this form preferable.

To sum up, intercepting sewers, which we require in the future, and also pipe-sewers, should be circular, but all others should be egg-shaped.

Considering the point, financially, it will be found that the latter will not add any expense. On the contrary, it will in many cases be cheaper. By having less width it decreases the amount of excavation; by substituting it for our present minimum size of 3 feet diameter, it would, by retaining the same height for the workmen to pass, also require less brickwork for nearly all cases, and by having a less span of arch, make it proportionately stronger.

If this is the conclusion, then nearly all of our sewers are improperly shaped. It would, of course, be entirely impracticable to replace them by others, although it may be advisable in a few cases. Yet many of them could be gradually so altered, at no great expense, as to sufficiently conform to the above demands. It would simply be

necessary to form a new invert inside of the sewer, without disturbing any part of it, either by means of half pipes backed by concrete or of concrete entirely, making a section somewhat like the Paris sewers, although much smaller, or the Fourteenth street sewer in Washington, D. C., where a similar plan was adopted.

To finally indicate the conditions of sectional shape for the *separate* system, it suffices to state that, according to what has been said, the sewers conveying sewage alone should be circular, and those for the rain-water can either be circular or, still better, egg-shaped, in order to give the diminishing quantity of water at the end of a rain the greatest possible flushing power.

(*b*) SIZE.—The sizes of our sewers have been determined by means of two considerations. First, they are proportioned to lead away an amount of storm-water equal to one cubic foot per second from every acre of the area, however large, which is equivalent to a rainfall of one inch per hour getting into the sewers. Secondly, the usual minimum size has been three feet in diameter. I shall consider these two points separately.

It is necessary to know the extent and magnitude of storms and the amount of water which flows into the sewers. Evidently, then, to have exact data on this question, so that the sewers will be neither too small nor too large is a matter of great economy. Special examinations have never been made in our city with reference to this matter, and, nowhere else have they yet been extended to limits which could be applied safely to all other localities. In order to proportion the size of our sewers in the most economical manner it would be necessary to make a series of observations, neither difficult nor very expensive to carry out, of the extent, intensity and duration of the heavy showers or storms passing over the city and its immediate vicinity, and a gauging of their effects in the sewers. The saving caused by such observations in obtaining rational sizes would be much more than would pay for their expense.

But until such local data can be procured we are left to obtain a guide from data collected at other places.

I have attached a table,* showing the duration and intensity of some heavy storms in Europe and in Philadelphia. By comparing, it will be seen that the intensity and duration of storms in Philadelphia are

*See Appendix No. 2.

certainly not greater than those elsewhere observed. We may, therefore, accept other experience to a certain extent as indicating what our own conditions might give. To appreciate the opinions held in Europe on the quantity of rain-water to be provided for I shall quote from the report of the Metropolitan Board of Works, 1878, p. 110, in the language of their celebrated engineer, Sir J. W. Bazalgette: "The intercepting sewers were not designed for the purpose of taking all the waters which fall during excessive rainstorms, such, for instance, as the one which occured on the 10th and 11th of April, 1878, when from observations made at forty-three stations in and around the metropolis, it was estimated that an average of 2·64 inches of rain had fallen over the whole of the metropolitan area within a period of nineteen hours. To intercept such a volume as resulted from this rain would have necessitated sewers of the capacity of rivers, and which would have been nearly empty, excepting an occasion of extraordinary fall."

A rainfall of 2·64 inches is according to this statement already considered excessive in London, yet there is a record of six inches having fallen in one and one-half hours.

The storm relief sewers which are being built and are further contemplated in London are proportioned according to Hawkley's formula:

$$\textit{Log diameter in inches} = \frac{3 \text{ log area in acres} + \text{log length in which the sewer falls one foot} + 6{\cdot}8.}{10}$$

It gives a diminishing quantity of rain running off per acre, as the area increases in size.

In no European city did I find the proportioning of sewers for a large area to be in a direct ratio with its size, as customary here. In fact our method elicited severe criticism.

If a sewer, according to our calculation, has a correct size at the lower end of the drainage area it will be too small near its higher part; and if its capacity is ample near the latter it will be unnecessarily large at the lower end. To suppose that the amount of water flowing off is in direct proportion to the area, although it is true for small ones, is not true for large ones measuring hundreds or thousands of acres.

Experience has amply shown that the amount of water reaching sewers from a certain rainfall depends: 1, on the size of the area, because the heaviest fall is not spread over a lage surface at the same

time, and its duration is not long enough to permit the water from the highest parts of a large area to reach the low ones before the rain has slackened; 2, on the general grade of the area, because the flatter it is the less velocity the water will have, and the greater will be the time for a portion to soak away; 3, on the character of the surface, whether it is urban or rural, paved or covered with buildings, gardens, lawns or fields, which also influences the amount that soaks away.

With these points in view, the experience gained has been framed in formulas of which one merits special attention. Mr. Burkli-Ziegler* carefully collected the known data on the subject and compiled them into the following formula:

The water reaching a sewer is equal to the average intensity of the rain during the period of heaviest fall, multiplied by a coefficient depending on the character of the surface, multiplied by the fourth root of the general grade of the area per 1000, divided by the area drained; or,

$$q = r \times c \sqrt[4]{\frac{s}{a}}$$

The coefficient $c = \cdot 75$, for paved streets and densely built up areas, graduates to $c = \cdot 31$ for suburbs with gardens, lawns, and macadamized streets.

This formula is compiled from observations made in London, Paris, and various parts of Germany and Switzerland, including rainfalls similar to our own, and slopes up to 10 feet per hundred and surfaces with city and country characteristics. Its results agree very closely with all the available data, and I consider it, therefore, a much better guide for us than the present "rule of three proportioning" of sewers.

To show the effect of this formula, I will apply it to our Mill Creek sewer at the lower end of its drainage area, which in round numbers is 3100 acres with an average slope of 5 feet per 1000. I shall suppose a rainfall at the rate of three inches per hour, the provision for which is as much as municipal economy will justify, and shall assume the coefficient depending on the nature of the surface to be ·50, which fairly represents suburban characteristics.

With these data we obtain the quantity of water reaching the lower part of the area.

*Burkli-Ziegler, *Abflussmengen städtischer Abzugscanäle*, Zürich, 1881.

$$q = 3 \times \cdot 5 \sqrt[4]{\frac{5}{3100}} = 3 \times \cdot 5 \times \tfrac{1}{8} = 0 \cdot 3$$

corresponding to about one-third of an inch per hour, which implies a size of only one-third of the present one, or a diameter of twelve feet instead of twenty. Observations which I have made of rainfalls during the construction of various parts of this sewer confirm this result.

It is thus evident that a great economy of expenditure is connected with this consideration.

If sewers are proportioned with the aid of this formula, or any other compiled from actual and varied experience, instead of by the rule of three, which has no confirmation in practice outside of very small areas, more rational sizes would certainly be obtained than at present, and a great saving of money effected.

After having considered the quantity of storm-water to be conveyed by sewers, which can have no overflows or relief channels, we must now consider what quantity of sewage is to be conveyed by sewers, which either receive no rain-water or only a small quantity, the rest escaping into other channels.

It is a usual custom in Europe, and it is generally found sufficiently accurate to consider the amount of sewage from a house to be equal to the amount of water supply furnished to it. And it is further assumed that one-half of the daily amount is discharged in six to nine hours. With this assumption the maximum flow of sewage can be obtained. For the separate system it would readily designate the size of the pipes, which, for safety, are usually considered as only half filled by sewage. For intercepting sewers, or any others with storm-water overflows, a small portion of rain-water, the first wash from the surface, should be allowed for. This quantity is usually assumed as $\frac{1}{50}$ to $\frac{1}{100}$ of an inch per hour, according to local conditions.

The formulæ used in Europe to determine the mean velocity of the sewage are Eytelwein's, Bazin's, Bazalgette's, and Kutter's, all of which, when properly used, were found to give sufficiently near and reliable results.

Regarding our minimum size of sewers which has been limited to three feet diameter, even to the summits where only two or three houses are to be drained, I have the following remarks to make: This limit was selected on account of being the least which will allow workmen to pass through to clean them. There is at present a divi-

sion of opinion regarding the expediency of having sewers large enough to be entered, or whether to use pipe-sewers, if the amount of water to be discharged will at all permit of the latter. As the difference of expense is often not great, it is preferred to make them passable. On the other hand, it is urged that to make them larger than necessary, impairs the rapidity of discharge and offers a storage for a large quantity of sewer gases. Pipe sewers are generally not used in Liverpool, Paris, and Vienna; in Frankfort and Hamburg, only under certain conditions, whereas in London and most English cities, in Berlin and Danzig, pipe-sewers are preferred wherever possible.

Their success depends on three elements, firstly, on faultless pipes of true dimensions and shape, secondly, on a faithful and careful laying, and thirdly, on a regular inspection, and in most cases, flushing. When these conditions can be obtained a pipe-sewer is superior to a larger one of brick, because of the smoothness of the perimeter, by which not only the velocity is increased but the adherence of decomposing matter greatly prevented.

When any of these conditions are not obtainable, and the slight additional cost for brick sewers is not objected to, the latter will generally be found preferable.

The proper course to be pursued in our city, therefore, is to lay pipe-sewers in preference, when good execution and maintenance can be commanded, otherwise or until then to build brick sewers of egg-shape three feet high in their stead.

The minimum diameter used for common pipe-sewers I found to be nine inches, for house branches usually six inches.

(*c*) GRADE.—I shall now examine into the proper grade of a sewer, which is of no less importance than the size.

It is commonly supposed that in many of our districts the gradients must naturally be very light, and that difficulties of drainage result therefrom, yet these difficulties are very slight, for we can give our sewers in any part of the city sufficient fall for a self-cleansing velocity. In Europe, 1:2000 to 1:3000 are common grades for main intercepting sewers, and 1:1000 for valley line sewers, whereas our usual minimum has been steeper than 1:1000. On the other hand, we have many heavy grades, some reaching five feet per hundred feet; and quite ordinary grades are one and two feet per hundred. In Europe, such grades have been shown to be very detrimental and destructive to the sewers, and were deprecated in many cities.

The great velocity created by a steep grade causes the silt carried by the sewage to scour the bottom to an injurious extent, as we have already noticed ourselves; for instance, at Twenty-third and Spring Garden streets, where some of the bricks were worn down three inches in six years by a grade of over four feet per hundred, causing a theoretical velocity of over twenty feet per second.

Mr. Rawlinson, the highest authority on modern sewerage, says* that the velocity in a sewer should not exceed six feet per second, and by considering this as a limit, a maximum gradient for each size can be obtained. This recommendation is generally acted upon, and I seldom found cases where grades were heavier.

Again, a steep gradient during the ordinary flow decreases the section of flowing water, and consequently injures its flushing capacity.

In steep sewers, therefore, we find banks of deposits at the sides of the streams between which it runs. In Berlin, this point was considered to be so serious that the maximum velocity in small sewers was limited to about four feet per second with corresponding grades, even when the ground permitted them to be greater.

A means to prevent a steep grade is to have occasional drops or tumbling bays, where the sewage suddenly drops vertically and then resumes its course. A series of steps, used sometimes for this purpose, was found to be much inferior to a vertical tumbling bay, with alternate drops, because the sewage can deposit more filth, and during storms, when the retarding action is most needed, it is least accomplished by them.

A *minimum* grade to be given will depend on the character of the sewage, whether carrying much silt or not, and also on the mass of water ordinarily flowing in them. The least bottom velocity should be sufficient to prevent a deposit of heavy silt. Numerous observations and tables have been recorded which can be used for this purpose, to which I refer.

In our city no distinction has been made between the grades for the ordinary and for the storm-water flows.

The grade producing the velocity of the ordinary flow, which is comparatively slight, may be assumed to be the same as the grade of the bottom of the sewer, which should be regulated accordingly and

*Suggestions of Local Government Board.

with attention to the points just mentioned. But the grade producing the velocity of the storm-water flow must be considered as being the surface of the water or the hydraulic gradient, especially near the outfall, where at high stages of the river, the sewer is partially or wholly submerged. In this case the velocity is always less than that produced by the grade of the sewer, and it may, therefore, seriously impair its capacity. The troubles of the Cohocksink Creek sewer are partially due to this cause.

At Pine street, near the Delaware, the six-foot sewer, west of Front street, might have been continued to the river, with the same size, instead of by means of a twin-sewer, chamber and rectangular outfall, if this question had been considered. And the Palmer street sewer might have been laid at its outlet to a much lower depth, without interfering in the least with its discharge, and thus saved the use of the property as a wharf.

Concerning the grades, when the sewage and rain-water are *separated*, nothing further need be added.

(*d*) DEPTH OF SEWERS.—But little is to be said regarding the depth of sewers. It is governed by the usual depth of cellars, as the sewers should always, if possible, be below them. As our cellars are generally five and six feet below the surface, the water in the sewers, allowing for a fall from the house, should not rise higher than seven to eight feet below the surface, according to which the depth of the bottom of the sewer can be regulated. In Europe, as a rule, the depth is greater, but the cellars are also deeper. In Frankfort, the average depth of the bottom of the sewer is seventeen feet below the surface, the deepest average I noticed anywhere.

In Philadelphia, the bottom has varied from nine to twelve below the ground, which, if the sewer does not hold more than two feet of water would generally be within the proper limits.

For the separate system the question of depth is important. The sewers proper must be as deep as those of the combined, so as to drain and protect the cellars. But the rain-water channels, being solely for the purpose of removing rain-water from the surface, can be as shallow as other considerations, the stability and grade will admit of. A great saving in the cost of excavation may therefore be secured for them.

(*e*) CONSTRUCTION.—The sewers in our city were formally built with much less care than at present, to which a large yearly percentage of breaks testifies. Lately, the main sewers have been built of

good materials and with sufficient care, so that their permanent stability is secured. The construction of the branch sewers, however, has only slightly improved, and the consequence cannot be otherwise than detrimental. The inverts are generally laid dry, or with so little and weak mortar that the effect is the same. The bricks used are usually warped and rough, presenting, when laid, a very uneven surface for the sewage to flow upon, and causing a considerable retention of decomposing matter. The four-inch ring used for a sewer of three feet diameter is, unless the work is very carefully done, not sufficient for stability, and a flattening of the arch, if not an actual collapse, is a common result.

The great difference in the construction of the sewers abroad is striking. The necessity of stability not only is fully appreciated, but also of giving the surface upon which the sewage flows the greatest practicable degree of smoothness, in order to avoid the retention of foul matter. As this is, perhaps, the most essential feature of good sewerage, its importance can hardly be over-estimated, and it cannot be too strongly urged upon our city. I have found that quite generally none but the best obtainable material was used, the hardest and most perfect-shaped bricks, the strongest Portland or Vassy cement, and the best and most carefully selected pipes. While inferior materials were sometimes admissible for works above ground, none but the best were allowed for sewers. The care given to the execution of the works, especially to make them water-tight, is correspondingly good. The more perfect sanitary condition of the modern European sewers is the natural result, and the economy of this care therefore becomes evident.

Regarding the thickness of materials for pipe, brick or other sewers, I refer to the accompanying drawings. It will be seen that for branch sewers better dimensions are used than here. Among the materials employed vitrified clay pipes of the best quality and true shapes are preferred for small sewers, up to fifteen inches in diameter, but seldom over this size. Iron pipes are used sometimes for house branches, and in Amsterdam even for the entire (Liernur) system. Bricks are the most common material used for large sewers. In nearly all cities they are wedge-shaped, at least for the arches and inverts. These cost but a trifle more and greatly increase the stability of arches between two and five feet diameters.

Bricks are wet before being used. They are laid in strong cement

mortar and carefully lined, and the joints are struck very smoothly, similarly to the back walls of our average dwelling-houses. Sewers are often built entirely of concrete, which material, as a rule, is preferred if within reasonable cost. A mould or centre of cast-iron, smoothly planed, is carefully aligned, the concrete stamped around it, and then left to set for several days. The best examples are found in Vienna, Paris and London where, especially in the first city, the inner surface in the best sewers was found to be as smooth as the average finished wall of a room.

The materials which will be economical in our city are vitrified pipes for sewers up to fifteen inches, or perhaps eighteen inches diameter, and bricks for the larger sizes. Concrete will hardly become advisable, because the clean, sharp gravel necessary for it is not found in this vicinity. The pipes should be very carefully selected, not only for hardness but for proper shape, so that no projections, bad joints or other imperfections will occur. The bricks should be of a better class, at least for the inner surface, to give a greater degree of smoothness to it. The mortar should be mixed with the best attainable cement, viz., the English or American Portland, or the better brands of Rosendale cement, with such proportions of sand as will secure a firm and hard set. Lime and cheaper cements are never used in Europe.

Regarding the execution of the work, it would be well to bestow greater attention than heretofore upon the three essential features in the construction of a sewer, viz., stability, water-tight joints and a smooth interior surface, which can be secured by proper dimensions and faithful labor.*

With these points held in view, our sewers could be brought up to standards, common not only in Europe, but also in some of our own sister cities, such as Providence, Boston, and New Haven.

(To be continued.)

*Bricks should have their joints carefully pointed after the centres are drawn, in branch as well as main sewers, and should never be laid dry, as this at once defeats the object of a perfect sewer, in allowing at certain times the sewage to soak into the surrounding soil similarly to a cesspool, which nuisance a sewer is precisely intended to abate. Pipe-sewers require even greater care on the part of the mechanic, because imperfections can more readily cause obstructions, and access to them is more difficult. But when properly built and maintained, pipes are superior to brick, as already mentioned, and the greater attention necessary in their execution is amply repaid, as shown by their being preferred in most European cities.

THE MANUFACTURE OF POTASH ALUM FROM FELDSPAR.

By Henry Pemberton, Jr.

[A paper read before the Chemical Section of the Franklin Institute, Sept. 5, 1882.]

In the August number of the Journal of the Franklin Institute there is an article by John Spiller (first published in the *Journal of the Society of Chemical Industry*, Manchester, England, April, 1882), in which it is proposed to manufacture potash alum from feldspar, by treatment with sulphuric acid and a fluoride, the latter being either fluorspar or cryolite.

Feldspar is a mineral occurring in immense deposits, and containing potash and alumina sufficient to give on a practical scale an amount of alum equal in weight to the quantity of feldspar treated. It can be had, under favorable circumstances, at a cost not exceeding a few dollars per ton. The fluorspar is equally cheap, and the sulphuric acid (as "chamber acid") is manufactured in this country at about $8 a ton. The resulting alum finds a ready market at $40 to $45 per ton, and the margin of profit, therefore, seems to be a very fair one.

I propose to show, however, that the above rosy view is a deceptive one, so far, at least, as the American market is concerned, and that the process is not only a technically difficult one, but will prove to be so expensive that the alum will cost about as much as it will bring.

Taking the typical feldspar selected by the author, we have, as its composition,

Silica,	65·00
Alumina,	17·85
Potash,	12·31
Iron, lime, magnesia, soda, etc., by difference,	4·84
	100·00

To volatilize the 65 per cent. silica as tetrafluoride will require 169 parts of fluorspar, supposing the latter to be chemically pure. We therefore will have the following percentages of bases and acid employed in treating 100 parts of feldspar:

17·85	per cent.	alumina,	requiring	42·00	per cent. SO_3
12·31	"	potash,	"	10·45	" "
169·00	"	fluorspar,	"	173·33	" "
	Total SO_3 required =			225·78	

This is equivalent to 443 parts of "chamber acid" containing 51 per cent. anhydride. The acid for the small quantity of other bases present is here neglected.

The author finds it "necessary to get rid of the excess of sulphuric acid by thoroughly heating the decomposed mass in a current of air before dissolving." Any one familiar with the behavior of alum at a high heat—especially when mixed with three times it weight of sulphate of lime—will fight shy of this operation on the large scale.

Mr. Spiller is perfectly right in asserting that there will be an excess of sulphuric acid in the decomposed mass, even when the quantity theoretically necessary is used. Experience has proved, in decomposing any solid material with acid in this manner, that from 10 to 15 per cent. of the material escapes the action of the acid, a corresponding amount of acid also being left uncombined. The reason for this being that the quantity of already decomposed material acts as a diluent of, and a mechanical separator between the remaining small quantities of acid and base. The most rational method of obviating this difficulty is to use a proportionally smaller quantity of acid. Charging the above formula, therefore, with only 85 per cent. of the acid given, and assuming that the feldspar, when mined, hauled, calcined (to render friable), ground and bolted, costs $5 per ton, and the fluorspar $3 per ton, we have, as the cost of the ingredients,

2000 lbs. feldspar, at $5.00, ...	$5.00	
3380 " fluorspar, at $3.00, ...	5.07	
7531 " 50°B. acid, at $8.00, ...	30.12	
		$40.19
Labor for mixing, leaching, evaporating, crystallizing and packing, with coal for evaporating, at least, . . .		5.00
Eight barrels, at 20c., ...		1.60
Yield = 2,000 lbs. alum, costing, . . .		$46.79

Or a little over 2¼c. per pound, not including general expenses, salaries, insurances, etc. This is just about the present market price for crystal alum.

It will be observed that the weak point in the above process is the quantity of acid required to liberate the fluorine from the fluorspar, nearly 80 per cent. of the acid charged being used for this purpose. About three tons of sulphate of lime, therefore, are formed, from this acid, for every ton of alum made. This bulky, insoluble, useless

material, has to be leached to extract the alum, requiring much water, giving weak liquors, and, consequently, wasting much coal in the subsequent concentration.

Recognizing these objections, Mr. Spiller proposes cryolite as the source of fluorine, in place of fluorspar.

This is an idea, if possible, still more unfortunate than the former one. In the first place, cryolite is expensive—exceedingly expensive when compared with the other materials used. In the second place, it yields the wrong alkali—soda, in place of potash. And, thirdly, even if the necessary potash were added (from Stassfurt salts), the resulting Glauber's salt—formed from the soda—would be left as a white elephant upon the hands of the manufacturer; all the whiter from the fact that it is contaminated to the saturation point with potash alum.

It is proposed to pass the fluoride of silicon, evolved from the above decompositions, into water, and to sell the resulting silica and hydrofluosilicic acid. As the alum industry is one amounting to hundreds of tons, whilst the most that can be claimed for the silica (for polishing powder) is that it can be disposed of by the hundreds of pounds, the odds against the silica are as 2000 to 1. Still less can be said for the hydrofluosilicic acid.

So it does not appear that there is much of value in Mr. Spiller's idea. It is true that his article was written for the English market. There the price for materials and labor is unquestionably lower than here. So also is the price the alum will bring. The argument against the process, therefore, will hold good in either longitude.

EDITOR JOURNAL FRANKLIN INSTITUTE:

The metal iridium has by reason of its extreme hardness and infusibility given great trouble to work. But comparatively recently Mr. John Holland, of Cincinnati, who had long been using the metal for the tips of gold pens, discovered how to drill and work it, and now he announces that he has made a 12-inch circular saw with teeth tipped with iridium—to be used for sawing hard wood. R. GRIMSHAW.

A CORRECTION.—ON THE ANALYSIS OF HELVITE.

By Reuben Haines.

[Read before the Chemical Sectiou, Franklin Institute, September 5, 1882.

Since the analysis of helvite from Amelia Court House, Va., was published in this journal (July, 1882), I have received from Mr. H. C. Lewis another sample of this mineral of much larger amount from the same locality. A re-examination of the specific gravity shows the previous determination to have been erroneous. It is now found to be 3·29. Dana gives the specific gravity as varying from 3·1 to 3·3. The error doubtless originated in attempting to work on too small a quantity of the mineral, less than three-tenths of a gramme having been used. For the determination now given 1·176 gramme were taken and the same portion afterwards used for general analysis. The material was very carefully picked over several times under a magnifying lens, and only the larger and more uniformly yellow-colored crystals selected. The largest of these, however, scarcely exceeded from one-twelfth to sixteenth of an inch in diameter. Mingled with the impure mineral sent me was a considerable amount of orthoclase felspar, to which some of the helvite adhered strongly, and also a number of crystals of pale-red topazolite (Lewis), a variety of garnet were observed mixed with the helvite, some adhering to the latter or partially imbedded in it.

A new analysis of the purified helvite gave total SiO_2, 32·49 per cent., of which the insoluble gangue was 5·17 per cent. The latter was determined on about half a gram of another portion of equally well-picked mineral by boiling the total unignited silica for some time in a concentrated solution of sodium carbonate. In the previous analysis I found total SiO_2, 32·32 per cent., and gangue 9·22 per cent. I am inclined to believe that the second determination of the gangue is the more correct of the two, chiefly because larger quantities were used and the treatment with sodic carbonate could be made more thorough. This gangue, obtained as residue insoluble in sodic carbonate solution and afterwards ignited with the filter and weighed, was examined microscopically with the polariscope and an interposed selenite plate. It was found to contain a very considerable proportion of unmistakable free quartz, much of which polarized very distinctly.

The remaining parts of the full analysis of this sample of the mineral have not yet been completed.

REPORT OF THE COMMITTEE ON SCIENCE AND THE ARTS ON THE FOWLER CLOTH CUTTING MACHINE.

HALL OF THE FRANKLIN INSTITUTE,
Philadelphia, April 3, 1882.

The Sub-Committee of the Committee on Science and the Arts, constituted by the Franklin Institute of the State of Pennsylvania, to whom was referred for examination Wm. R. Fowler's Cloth Cutting Machine, report that (at a meeting held on Monday evening, March 27, 1882, at the Institute, at which a majority of the members of the committee were present) they carefully examined a working model of the Fowler Machine, and find that the following claims are worthy of merit, *e. g.:*

The "cutters" or more properly the cutting knives, both the single and double.

The cutting bed.

The work holding device.

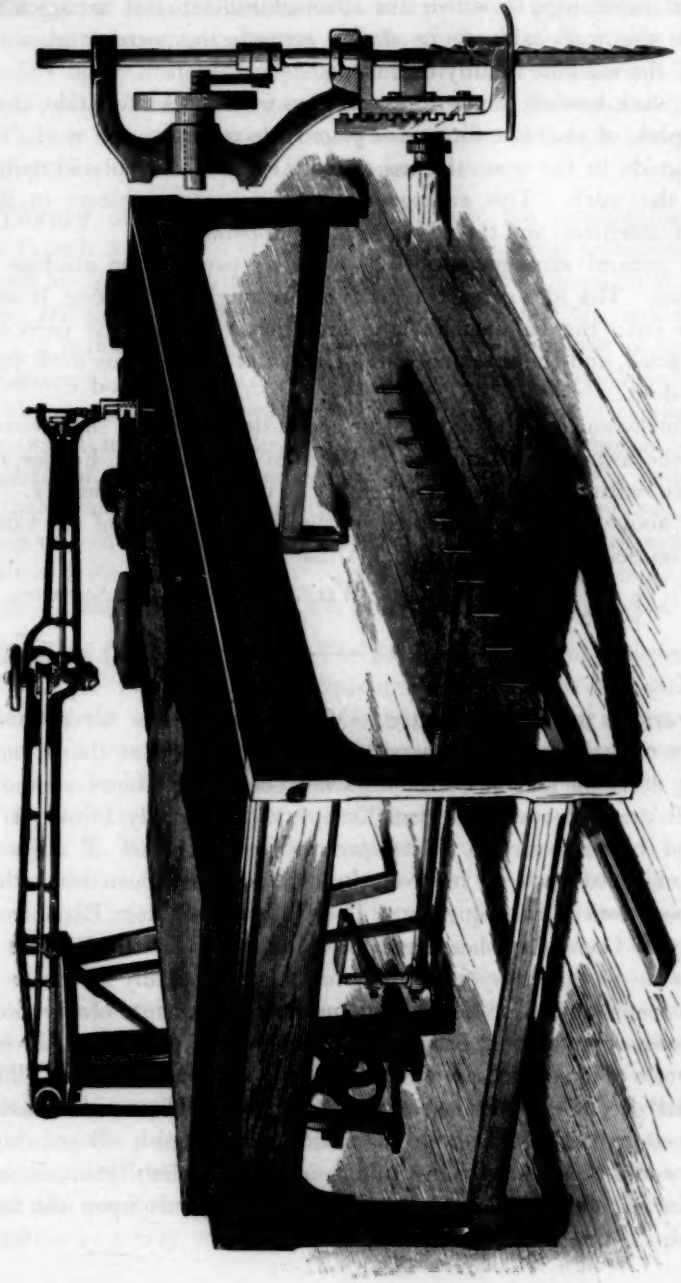
1st. The cutters are made either single or double, having a single cutting edge, or several of these edges, so sharpened as to cut *only* upon the *up-stroke*, having the portion below the said edge reduced in width, or tapered, so as to present a narrow tongue at or near the lower end of the blade, thus forming a strong, durable cutter; the blunt lower end projects beyond the cutting edge, thus protecting it. The series of projections or sharpened edges of the double knife recede from the lower to the upper portion of the knife in step-like form.

The knives when working make 1500 strokes per minute and are made long enough to cut through 4 inches of cloth, and perform their work well.

The knives can be easily ground.

2d. The cutting bed consists of steel wires of sufficient length, set into "blocks" at regular intervals apart, and secured to a backing; the upper ends of wires rounded off. The regular spaces between the wires permit the traversing of the knife in accordance with any pattern marked upon the cloth. From the elasticity of the wires the knife cannot catch upon them, the blunt edge of the knife coming in contact with the wire, slips to one side by bending the wire slightly out of normal position.

This "sectional" bed is inclosed in a rectangular frame resting upon



FOWLER CLOTH CUTTING MACHINE.

four or more legs, to which are attached rollers; this arrangement permits the work-table to be drawn towards the operator when the arm of the machine is fully extended.

The work holding device, in connection with the knife guide, abutment plate of skeleton form, are placed above, upon the work, the knife guide in the general class of cloth cutters being placed underneath the work. This arrangement *above* is a new feature in this class of machines, and the advantages are apparent.

The general arrangement of the working parts of the machine is excellent. The idea of making it light in weight, but strong, is well carried out; the balancing of the arm good; the various parts are nicely fitted, and the machine works easily and performs its work very well indeed.

In furtherance of the above, your committee state that they recommend the award of a Diploma of Merit to Mr. Wm. R. Fowler for his cloth cutting machine, for ingenuity in design and originality.

The above report was adopted at the stated meeting of the Committee on Science and the Arts held June 7, 1882.

WILLIAM H. WAHL, *Secretary.*

Reversals of Temperature.—M. Alluard records several comparative observations in January and February, 1882, at the summit of Puy de Dome and at Clermont, which show that whenever an area of high pressure covers Central Europe, and especially France, it is attended by an inversion of temperature with increase of altitude. Arago observed such an inversion in 1839, and the phenomenon has often been noticed subsequently. The visibility of Mont Blanc from the Puy de Dome furnishes a means of studying the distribution of densities in the lower layers of the atmosphere, especially at epochs of the phenomenon in question. Faye proposes to institute observations upon geodesic refraction, between the summits of the Puy de Dome and certain points which are easily accessible upon Mont Blanc. The beautiful geodesic operations of the French War Department, under the direction of Col. Perier in connection with Spanish officers, show that it would be possible to institute reciprocal and simultaneous measurements of zenith distance between luminous signals upon the two mountains.—*Comptes Rendus,* xciv, 1175. C.

Cause of Scintillation.—Jamin attributes scintillation to the continually changing curvature of the surfaces of luminous waves. He has lately made an extended series of observations with Arago's scintillometer, which confirms the theory of Cooke, Newton and Young, while they discredit that of Arago, who attributed the phenomenon to the interference of waves.—*Les Mondes.* C.

Theory of Rapid Navigation.—Pictet has communicated to the French Academy a summary of the mathematical principles upon which he is constructing his experimental boat. The essential conditions are the following: 1. The volume, of which the equation $F(x, y, z)$ is the exterior surface below the water line, must be equal to the tonnage, T. 2. The integral of the elementary surface multiplied by the sine of the angle, which is made by the element of surface with the axis of translation, must be a minimum. 3. The resultant of the mechanical action of the water against the keel must be a maximum in the direction which is opposed to gravity and a minimum in all other directions. 4. The motive power must be calculated so that its efficient force may be superior to the integral of the resistance of the water for the least velocity which is desired.—*Comptes Rendus.* C.

French Observatories.—The French government, together with the city of Paris, has voted appropriations and given ground for enlarging the operations of the city observatory. The streets which have been opened in the neighborhood have caused the erection of numerous buildings, which threaten to shut out a considerable portion of the horizon, and thus interfere seriously with the work of the observatory. M. Wolf has called the attention of the authorities to these matters, but it seems doubtful whether any effectual remedy can be devised. The new observatory of the Pic du Midi has been completed, and all the instruments have been removed from the old stations, which have been occupied for seven successive winters. A covered subterranean passageway has been built between the dwelling and the platform for the instruments, in which there is a work-shop, a stable and storehouses, together with provisions for various underground observations. A subterranean telegraphic cable has been carried to the summit, which has worked without any interruption by the storms to which the peak is subject. The extent of view, together with the purity and transparency of the air, are likely to make the observatory a very valuable one.—*Gironde.* C.

The Coming Transit of Venus.—A conference of thirty distinguished astronomers, from various parts of the world, has been lately held in Paris, under the presidency of J. B. Dumas, perpetual Secretary of the French Academy. Eight stations of observation were selected; methods of observation were decided, upon and regulations established for the observation of contacts. Before separating, the conference expressed a wish that the French government would come to a definite understanding with other governments for the creation of a temporary international bureau, in order that the results of the observations may be made known as speedily as possible.—*Les Mondes.* C.

Photographs of Flying Birds.—M. Marey has succeeded by instantaneous photography and with the help of a photographic revolver similar to the one which was contrived by Jansen for observing the transit of Venus in obtaining a complete analysis of different forms of locomotion, including the flight of birds. More than two years ago, Muybridge obtained fine pictures of running horses which were photographed in $\frac{1}{500}$ part of a second. He also photographed flying pigeons, but could only get a single picture. Marey has been able to obtain a dozen successive pictures in a second, each exposure requiring only $\frac{1}{700}$ of a second. By arranging the pictures in a phenakistiscope the appearance of the flying bird may be reproduced, under conditions which permit the analysis of different phases of the wings.—*Chron. Industr.* C.

Effects of Cold upon Chrysales.—M. Colasanti has tried the influence of cold upon butterflies and their chrysales. He submitted cocoons, for forty-eight hours, to a temperature of —12° (9·°4F.), so that they were entirely frozen. Then he kept them in a chamber at the ordinary temperature, and the butterflies came out at the proper time, perfectly organized. He afterwards submitted the butterflies themselves to the same temperature. At the end of five minutes they had fallen into a lethargy and soon afterwards they were frozen and stiff as a bit of ice. Those which were weakest were the first to feel the effects of cold. Within ten or fifteen minutes after they had been withdrawn from the low temperature they resumed their normal functions. He subjected the same butterflies to the same degree of cold at three different times, with similar results, but they became gradually more feeble, and they would probably have died if the experiment had been often repeated.—*Les Mondes.* C.

A New Wheel.—Signor Gaetano Contro has invented a new carriage-wheel, in which the iron rim is united to the hub by semi-circular steel spokes. The curvature allows them to serve both as spokes and as springs. The result of experimental trials is said to have surpassed the anticipations of the inventor. In great speed, especially, the irregularities of the soil produce no shock. Elasticity, solidity, and complete absence of noise are enumerated among the special advantages of the new invention.—*Les Mondes.* C.

Use of Electricity in Laboratories.—The halls of the five laboratories of the Scientific School at Aix la Chapelle are heated by air, and the temperature is regulated by electric thermometers which transmit automatic signals to the heater: *too cold*, when the temperature is below 17° (62·6°F.); *too warm*, when it exceeds 19° (66·2°F.). The absence of the care-taker has been provided for by call bells, which are operated at the same time as the indicators The great amphitheatre can be lighted either by gas or by the electric light from a Siemens' machine. On removing a panel, behind the Professor's table, a ground glass is exposed which facilitates the use of the electric light for projecting chemical or physical experiments. A quantity machine is employed for electrolytic precipitations. Conductors bring the currents into the laboratory of quantitative analysis and into the the grand amphitheatre.—*D'Electricien*, iii, 47. C.

New Map of the Milky Way.—M. Faye commends the new map of the milky way which has been published in the annals of the Brussels observatory by means of curves of equal luminous intensity. The path forms an almost perfect great circle of the celestial sphere and all the brightest stars, as well as those which are telescopic, appear to be concentrated towards it. The solar system is situated almost exactly in its plane and probably near its centre. The map has the merit of extending to the stars which are visible to the naked eye the results which had already been obtained by Struve for the telescopic stars, and of clearing up in a remarkable manner the present confused notions about the milky way. It seems desirable to calculate the galactic coordinates of the stars and nebulæ as well as their circular variations. The annals give a catalogue of 76 determinations of the sun's parallax, extending over a period of 21 centuries. The mean of the 55 most recent determinations 8.″82, which is precisely the result that Faye had obtained from nine independent methods.—*Comptes Rendus.* C.

Rotary Electric Coefficients of Metals.—Dr. E. H. Hall, of Baltimore, communicated a paper to the British Association upon his electric discovery, giving calculations of the degree of rotation produced by a unit of section of varions substances; some of the rotations being positive, others negative. Sir Wm. Thompson regarded the communication as the most important that has been made to electrical science since the days of Faraday. It would be interesting, in view of the nature of electricity and of the properties of matter, to know whether there is a direct action of the magnetism upon the current, or whether the action is upon the distribution of the material molecules, changing the molecular constitution and thus changing the conditions of the propagation of the current.—*L'Electricien.* C.

Metallic Cæsium and Rubidium.—The discovery of cæsium and rubidium was one of the first triumphs of spectrum analysis. They are the most electro-positive of all the known elements; their affinity for oxygen is so great that it has hitherto been impossible to obtain cæsium in the metallic state. The problem, however, has just been resolved by M. Lettenberg by the electrolysis of a melted mixture of cyanide of cæsium and cyanide of barium, of which the experimenter obtained a large quantity at an enormous price. Cæsium is like the other alkaline metals, of a silvery whiteness, very soft and very ductile. Its melting point is 25·°3 (77·°54 F.), and its specific gravity 1·88. It inflames spontaneously in the air, and when thrown upon water it behaves like sodium, potassium and rubidium.—*Les Mondes.* C.

Pompeian Surgery.—Every one who has visited the ruins of Pompeii knows the house of the surgeon, and has heard of the numerous surgical instruments which were found in it at the moment of excavation. Nearly every instrument is now in use, especially in country practice. When we remember that Pompeii was not a city of the first class, but a simple municipality, a borough of small importance in comparison with Naples, it seems remarkable that the Pompeian surgery should have been as thorough and as scientific as it is at the present day in French towns of similar magnitude. The fact is perhaps partly attributable to the influence of the neighboring schools of Magna Græcia, and yet whenever chance permits us, as at Pompeii, to spend a day with men of a former age there is always occasion for surprise that so little change has been made in the most important details of domestic life.—*Les Mondes.* C.

Has the Earth a Fluid Nucleus.—F. Folie proposes an astronomical criterion for settling the question whether any portion of the interior of the globe is fluid. He finds that Laplace and Poisson have entirely neglected, in their integrations, certain terms which have a period of a day or of a fraction of a day. These terms would lead to a diurnal nutation, which could be approximately calculated if there is any considerable portion of melted matter about the centre of the earth. Supposing that hypothesis to be true, the determination of the right ascension of stars which are situated as near as possible to the poles should give different values at different hours of the day, especially at epochs when the longitude of the sun and moon is 90°. Folie invites the attention of astronomers to this subject, especially of those who have a good altazimuth, which will enable them to follow the movement of a star and to make precise determination of its position at every quarter of an hour in its diurnal revolution.—*Bull. de l'Acad. de Belg.* C.

Magnetic Purification of Porcelain Paste.—There is a difference in commercial value of 40 per cent. between pieces of porcelain which are absolutely white and those which present the slightest spot. The spots are produced by small quantities of ferruginous matter, of which the chemical composition is not well known, but which can be attracted by a magnet. Many attempts have been made to use magnets systematically, but they have hitherto been unsuccessful. Two French establishments have lately employed the following method with very satisfactory results. Each electro-magnet is composed of two coils placed in a line; their remote ends are connected by a long piece of iron; the two near ends are but a short distance apart, one representing the north pole and the other the south pole of the electro-magnet; between them there is a magnetic field which can be made very powerful, provided there is a sufficient exciting current. A tight box encloses this magnetic field; it is open above, and has a round opening below into which an escaping tube is inserted. The porcelain paste, very liquid, running into the box, encounters a small zinc diaphragm which sends it to the right and to the left over the polar faces; the magnetic particles are retained and the rest escapes. The polar surfaces are cleansed twice a day by a jet of water. The apparatus may be worked either with a Gramme machine or with a battery.—*L'Electricien.* C.

Franklin Institute.

HALL OF THE INSTITUTE, September 20, 1882.

The stated meeting of the Institute was held this evening at the usual hour, with the President, Mr. Wm. P. Tatham, in the chair.

The minutes of the last meeting were read and approved.

The Actuary submitted the minutes of the Board of Managers, and reported that since the last meeting of the Institute 12 persons had been elected members. He likewise reported the action of the Board in reference to the death of Mr. Robert Briggs.

The President, after an allusion to Mr. Briggs' long and active connection with the Institute, suggested the propriety of appointing a committee to prepare a suitable memorial.

A motion to this effect was made and carried.

The Committee on Meetings, to whom had been referred the subject of the revision of the order of business, reported progress.

The Special Committee on "Fires in Theatres" reported progress and was continued.

The Special Committee on "Patent Legislation," through Mr. Thos. Shaw, the Chairman, made a report, which was signed by a majority of the committee.

On motion of Mr. Burk the report was adopted and the committee was discharged with the thanks of the Institute.

Mr. William E. Lockwood then read a paper "On the Shaw Locomotive," illustrating the same by means of a model engine, specimens and models of various parts of the mechanism, and numerous lantern slides. The paper was attentively listened to, and provoked a lengthy discussion, which was participated in by Messrs. Strong, Shaw, Burk, Cooper, Cox, Whitney and the author. Mr. John W. Cloud, of Altoona, gave, by invitation, some interesting explanations of theoretical and practical points bearing on the subject.

The Secretary's report embraced a brief *résumé* of the proceedings of the American and British Associations for the Advancement of Science; a description of the application of the Secondary Battery to the lighting of cars of the Pennsylvania Railroad Co.; of the progress of the Hudson River Tunnel, and a description, with lantern illustra-

tions and model, of the Cable System of Street Railways, with especial reference to the cable road now in course of construction on the Columbia avenue extension of the Union Passenger Railway Co.

An invitation was extended to members to visit the officers of the Levett-Müller Electric Light Co., 1003 Chestnut street, on Thursday evening, September 21st, to inspect the operation of the system and to witness the working of a magnetic ore separator.

The following mechanical inventions were shown and described: Ives' Improved Ether-Oxygen Apparatus for the Lantern, in which the hydrogen element is furnished to the blowpipe by dividing the oxygen supply and passing a portion of it through ether, so that it becomes saturated with ether vapor; the mixture burns like hydrogen or coal gas, and the flame is brought to a focus by admitting some oxygen in the usual manner. The saturater has a cotton filling which absorbs the ether, so that none will spill into the tube if it is upset.

The Cumming Periphery-Contact Disc Electrodes consist of two wheels used as electrodes or contact points placed at right angles to each other and impinging on their peripheries. The size of the contact is a mere dot, which is still further reduced by each wheel having a rounded edge consisting of a platinum wire rim run into a groove in the periphery of a brass wheel. The invention is applicable to a great variety of electrical machinery.

A Water Gauge Reflector for Steam Boilers was shown, consisting of a highly polished metallic mirror placed behind and partly surrounding the usual water gauge. It enables the attendant to see the height of water in his gauge glass clearly even in a comparatively dark room.

Specimen Water Meters, manufactured by the Union Water Meter Co., Worcester, Mass., and by the National Water Meter Co., New York, were shown, as were also the Atwood Safety Nut, and the Harvey Manufacturing Co.'s Spiral Wedge, or self-fitting nut.

The President announced that he had appointed Messrs. Henry G. Morris (chairman), B. C. Tilghman, and Henry R. Towne to serve as a committee to prepare a memorial of Mr. Briggs.

Upon which the meeting was adjourned.

WILLIAM H. WAHL, *Secretary.*

List of Books Added to the Library during July, August and September, 1882.

Agriculture of Pennsylvania. Reports for 1881. Harrisburg.
Presented by Hon. G. W. Hall.

American Iron and Steel Association. Annual report of Secretary for 1881. Philadelphia. Presented by the Association.

Apprentices' Library Company. Philadelphia. Sixty-second Annual Report of the Managers for 1882. Presented by the Company.

Auditor-General's Report on the Finances of Pennsylvania for 1881. Harrisburg. Presented by Hon. G. W. Hall.

Births, Marriages and Deaths in Michigan for the year 1876. Tenth Report. Lansing. Presented by H. B. Baker, Superintendent.

British Association for the Advancement of Science. Report for 1881.
Presented by the Association.

Census Bureau, United States. Statistics of Power and Machinery employed in Manufactures. Washington.
Presented by the Bureau.

Cotton Exposition at Atlanta. 1881. Report.

Couche M. Ch. Voie Matériel Roulant et Exploitation technique des Chemins de Fer. Text and Plates. Paris. 1867—1876.

Dictionarium manuale Latina–Hispanum ad usum puerorummatriti. 1882. Presented by L. S. Ware.

Encyclopædia Britannica. Vol. 14. Boston. 1882.

Engine, Boiler and Employers' Liability Insurance Company. Engineer's Report for 1882. Presented by the Company.

Engineer Department, U. S. A. Annual Report of the Chief for 1881. Washington. Presented by the Department

Frazer, P. Thèses presentées a la Faculté des Sciences de Lille pour obtenir le grade de Docteur ès—Sciences Naturelles.
Presented by the Author.

Gauchez, W. V. Conferences sur l'application du Mouvement de la Mer. Bruxelles. 1881. Presented by the Minister of War.

Gilbert, F. Life of J. Wood. Chicago. 1882.
Presented by the Author.

Health Bulletins issued by Supervising Surgeon-General. Reprint. Washington. 1881.
Presented by the Supervising Surgeon-General.

Hering, R. System of Main Sewerage for City of Cleveland. 1882.
Presented by the Author.

Hoernes, R. und Auinger, M. Die Gasteropoden. Wien. 1882.
Presented by the K. K. Geol. Reichsanstalt.

Industrial Exhibitions. Cincinnati. Reports of the Ninth and Tenth. 1881—1882. Presented by W. H. Stewart.

Institution of Civil Engineers of Ireland. Vol. 13. Dublin. 1882.
Presented by the Institution.

Institution of Civil Engineers. Proceedings. Vol. 68. London.
Presented by the Institution.

Internal Affairs of Pennsylvania. Annual Report of the Secretary. Parts 1—4. Harrisburg. 1881.
Presented by the Hon. G. W. Hall.

Interior Department. Contributions to North American Ethnology. Vol. 4. Washington. Presented by the Department.

Meteorological Charter for the Ocean District adjacent to the Cape of Good Hope. Presented by the Royal Society.

Meteorological Department of India. Report on the Administration. 1880—1881. Presented by the Government of India.

Meteorological Observations recorded at Six Stations in India, in 1880—1881. Presented by the Meteorological Office.

Meteorology of India. Report for 1879.
Presented by the Government of India.

National Board of Health. Annual Report for 1879.
Presented by the Board.

Navy Department. Annual Report of the Secretary for 1881. Washington. Presented by the Department.

Navy Department. Sanitary and Statistical Report of the Surgeon-General for 1880. Washington.
Presented by the Surgeon-General.

New Jersey. Geological Survey. Annual report of the State Geologist for 1881. From the State Geologist.

New York State Survey. Report of Director for 1880.
Presented by the Director.